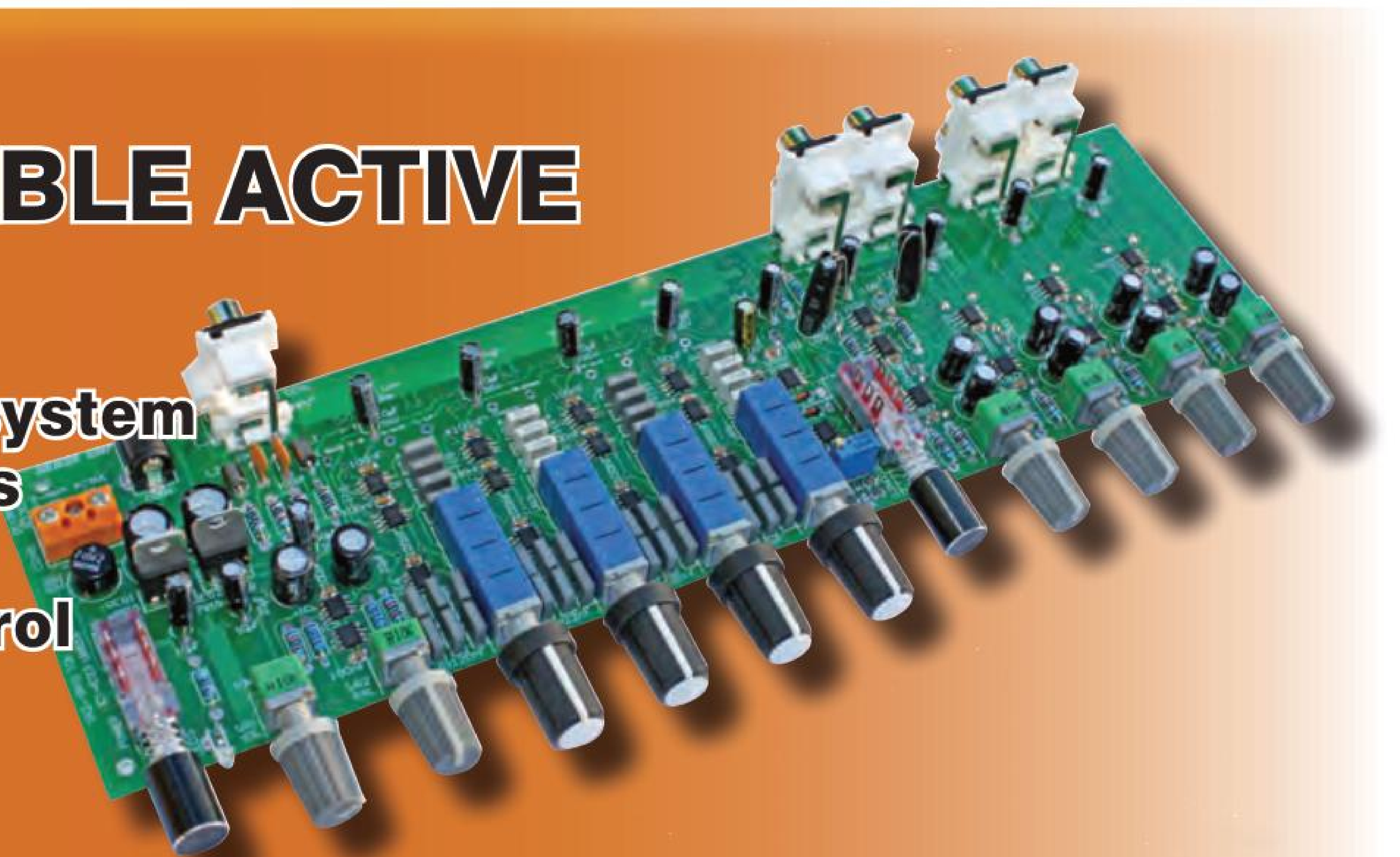
THE No 1 UK MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

EPE EVERYDAY PRACTICAL ELECTRONICS

www.epemag.com



3-WAY FULLY ADJUSTABLE ACTIVE CROSSOVER – PART 1

- Perfect for your stereo speaker system
- Adjustable crossover frequencies
- 3- or 2-band operation
- Overall volume and balance control

DEAD-EASY SUPERHET IF ALIGNMENT USING DIRECT DIGITAL SYNTHESIS

ELEGANT MICROMITE-BASED SOLUTION TO AN AGE-OLD RADIO PROBLEM

SUPER
SUMMER
SALE

AD9850-BASED DIRECT DIGITAL SYNTHESISER

Learn to use this superb SPI-controlled module

WIN A
MICROCHIP
SAMA5D27-SOM1-EK1
Development
Board

TOUCHSCREEN APPLIANCE ENERGY METER

Part 3 – Calibration and using your meter

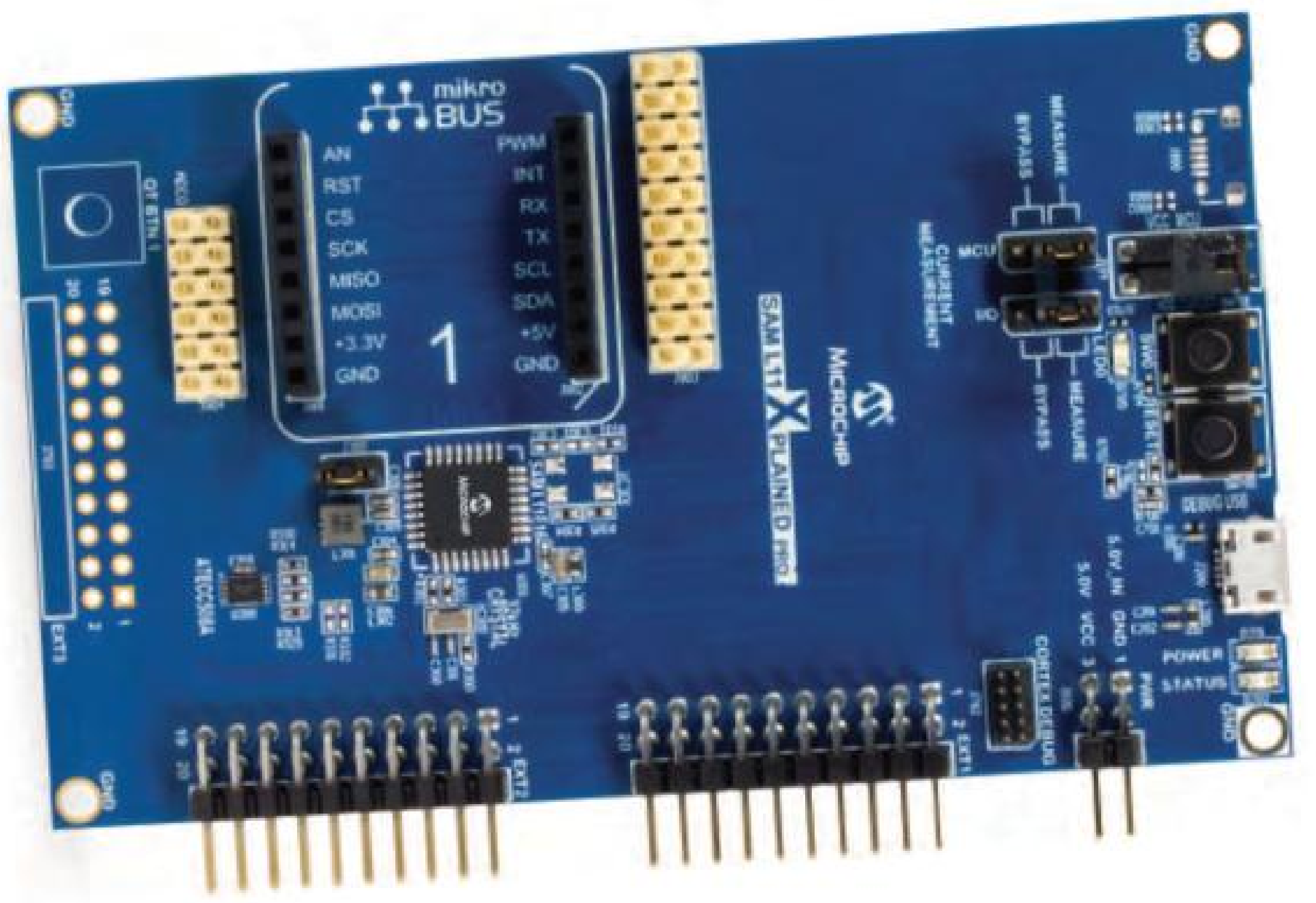
ELECTRONIC BUILDING BLOCKS, NET WORK, AUDIO OUT, TECHNO TALK, CIRCUIT SURGERY, LUCY'S LAB & PIC n' MIX

SEP 2018 £4.65
09
9 770262 361195

MICROCHIP

Development Tool of the Month!

SAML11 Xplained Pro Evaluation Kit



Part Number
DM320205

Overview:

The SAML11 Xplained Pro evaluation kit is ideal for evaluating and prototyping with the ultra low power SAML11 ARM® Cortex®-M23 based microcontrollers integrating robust security which includes ARM® TrustZone®, secure boot, crypto acceleration, secure key storage and chip-level tamper detection. In addition to security the SAM L11 MCU features general purpose embedded control capabilities with enhanced peripheral touch controller and advanced analog.

Key Features:

- SAM L11 32-bit MCU:
  - 32 MHz Arm Cortex M23 Core
  - 64 KB Flash and 16 KB SRAM
  - Chip-level security
  - Arm TrustZone
  - Industry's lowest power MCU in its class
  - Enhanced PTC
  - Op Amps, ADC, AC, Analog Compare
  - ISO7816
- Xplained Pro extension headers
- mikroBUS socket
- X32 header
- Embedded debugger
- USB powered

Order Your SAML11 Xplained Pro Evaluation Kit
Today at: www.microchipdirect.com

microchip DIRECT
www.microchipdirect.com

MICROCHIP

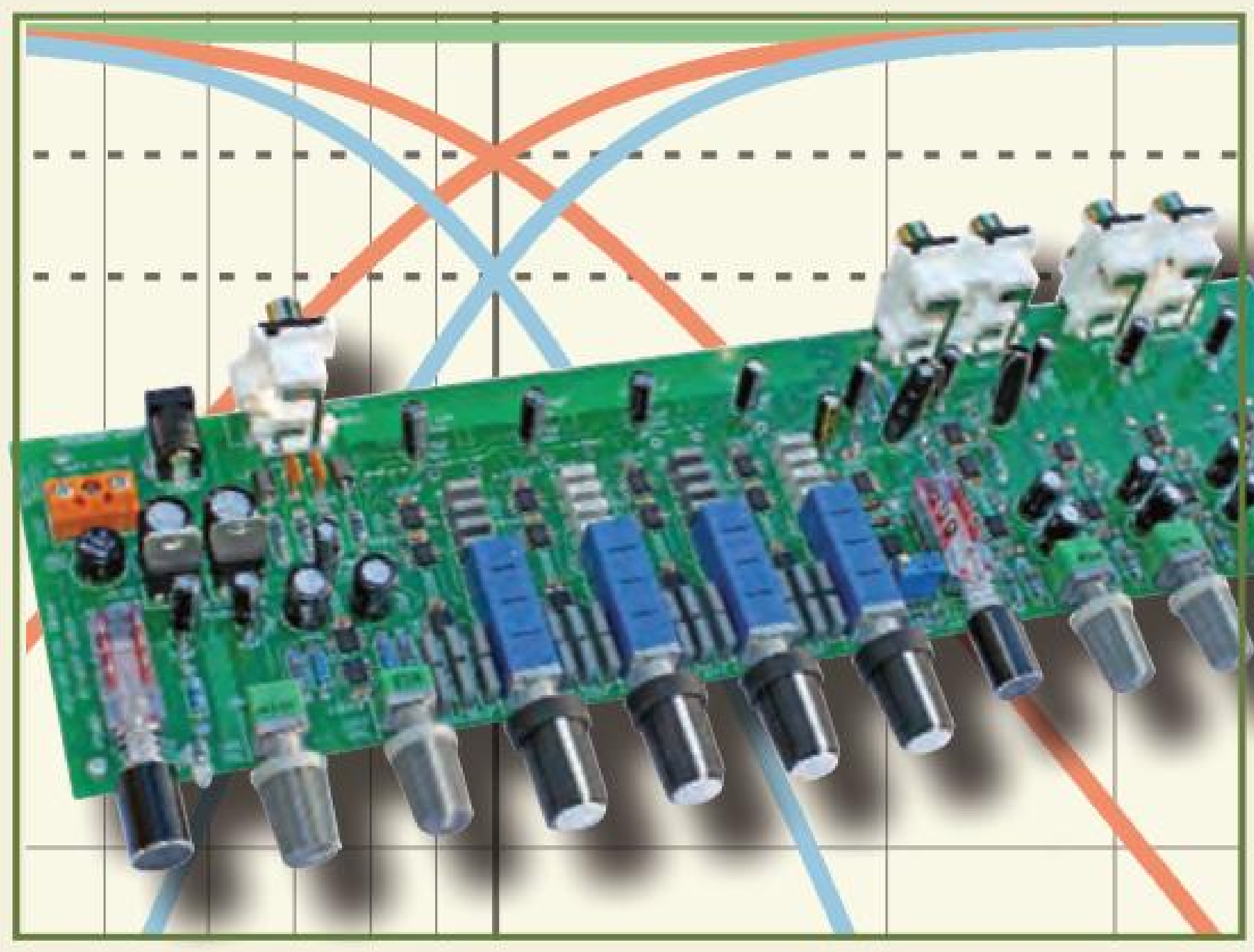
The Microchip name and logo, PIC and MPLAB are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks mentioned herein are the property of their respective companies.
© 2018 Microchip Technology Inc. All rights reserved. MEC2216Eng07/18

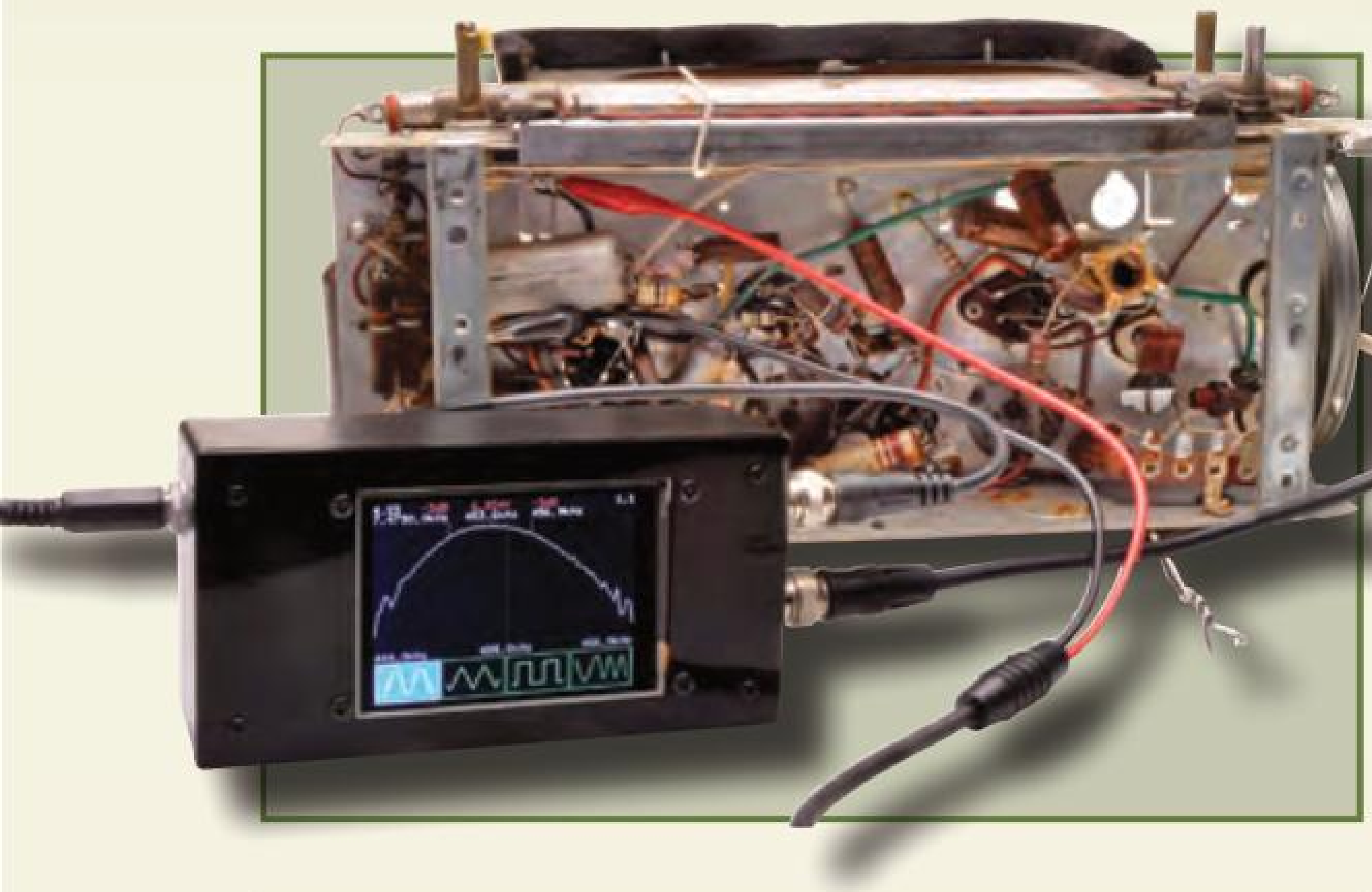
ISSN 0262 3617
● PROJECTS ● THEORY ●
● NEWS ● COMMENT ●
● POPULAR FEATURES ●
VOL. 47. No 9 September 2018

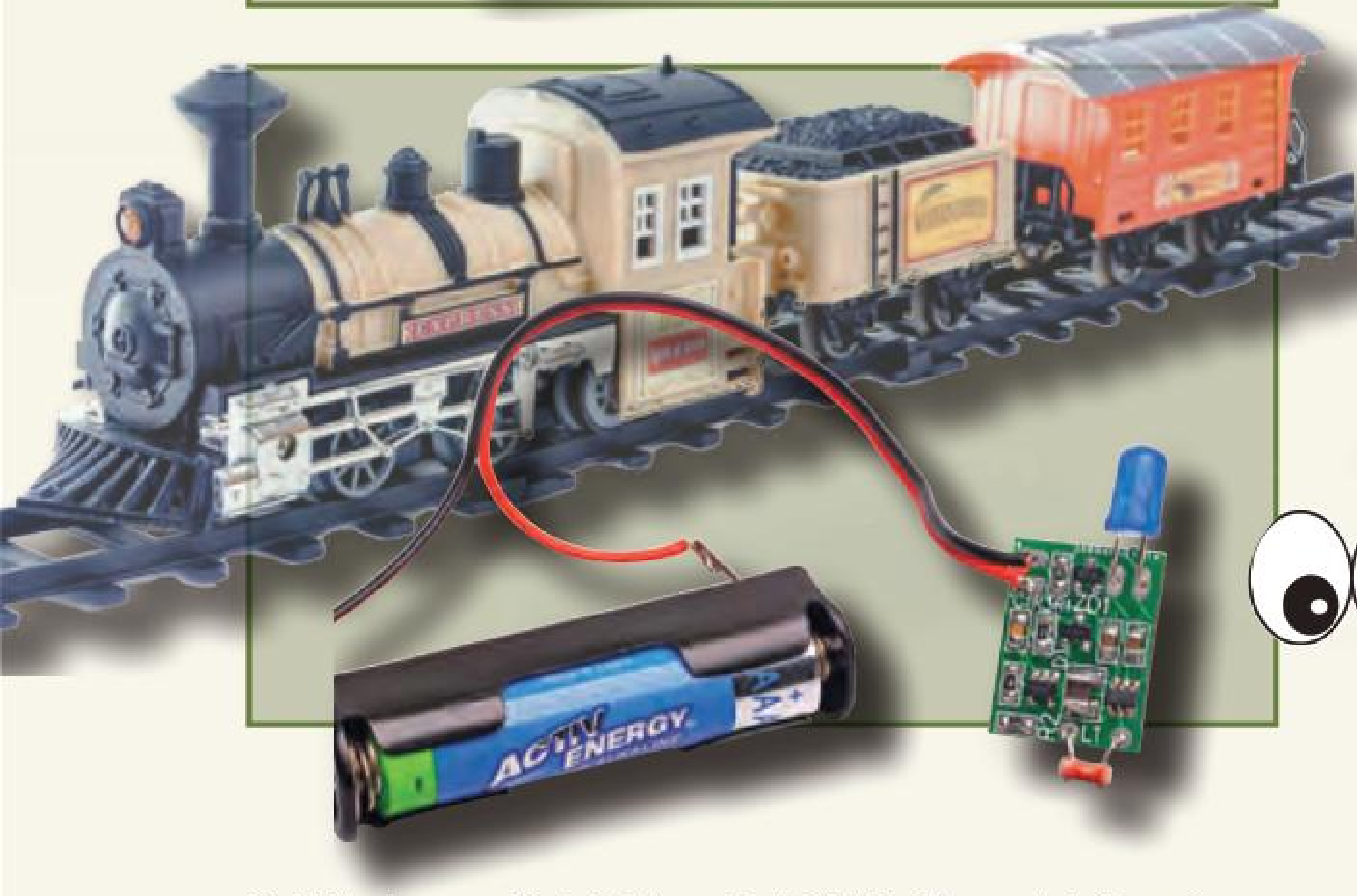
EPE EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL

www.epemag.com







Projects and Circuits

3-WAY FULLY ADJUSTABLE STEREO ACTIVE CROSSOVER FOR LOUDSPEAKERS – PART 1 12
by John Clarke
This superb project is not only a fantastic tool for loudspeaker development and design, but can also be integrated into 2-way or 3-way active loudspeakers.

DEAD-EASY SUPERHET IF ALIGNMENT USING DIRECT DIGITAL SYNTHESIS 22
by Nicholas Vinen
Use the Micromite DDS Signal Generator to align IF stages in superhet sets.

TOUCHSCREEN APPLIANCE ENERGY METER – PART 3 28
by Jim Rowe and Nicholas Vinen
In the third and final part of the project, learn to calibrate and use your meter.

ULTRA-LOW-VOLTAGE MINI LED FLASHER 34
by Nicholas Vinen
Versatile design using a handful of components to flash any LED with just 0.8V.

USING CHEAP ASIAN ELECTRONIC MODULES – PART 9 40
by Jim Rowe
Learn to use the AD9850 Direct Digital Synthesiser (DDS) chip.

Series and Features

TECHNO TALK by Mark Nelson 11
Time for a rethink?

LUCY'S LAB by Dr Lucy Rogers 39
Gather round the Wi-Fi

NET WORK by Alan Winstanley 46
Your Facebook history... A YouTube dilemma... Chrome plated

PIC n' MIX by Mike O'Keeffe 48
PICMeter Part 1 – Introduction to the Voltmeter

CIRCUIT SURGERY by Ian Bell 52
Differentiator circuits

AUDIO OUT by Jake Rothman 56
Analogue synthesis – Part 2

ELECTRONIC BUILDING BLOCKS by Julian Edgar 68
Three Great Buys!

SUPER
SUMMER
SALE

Regulars and Services

SUBSCRIBE TO *EPE* and save money 4

***EPE* SUMMER SALE –** a page full of great deals 5

EDITORIAL 7
Introducing the PICMeter… The computer will see you now

NEWS – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics

MICROCHIP READER OFFER 21
EPE Exclusive – Win a Microchip SAMA5D27-SOM1-EK1 development board

***EPE* BACK ISSUES CD-ROM** 33

EPE TEACH-IN 8 45

***EPE*/MICROCHIP PICKIT 4 OFFER** 51

***EPE* CD ROMS FOR ELECTRONICS** 62
A wide range of CD-ROMs for hobbyists, students and engineers

DIRECT BOOK SERVICE 65
A wide range of technical books available by mail order, plus more CD-ROMs

***EPE* PCB SERVICE** 70
PCBs for *EPE* projects

ADVERTISERS INDEX 71

NEXT MONTH! – Highlights of next month's ***EPE*** 72

© Wimborne Publishing Ltd 2018. Copyright in all drawings, photographs and articles published in *EVERYDAY PRACTICAL ELECTRONICS* is fully protected, and reproduction or imitations in whole or in part are expressly forbidden.

Our October 2018 issue will be published on Thursday 6 September 2018, see page 72 for details.

Readers' Services • Editorial and Advertisement Departments *7*

Quasar Electronics Limited
PO Box 6935, Bishops Stortford
CM23 4WP, United Kingdom

Tel: 01279 467799
E-mail: sales@quasarelectronics.co.uk
Web: quasarelectronics.co.uk

All prices INCLUDE 20.0% VAT. Free UK delivery on orders over £48
Postage & Packing Options (Up to 0.5Kg gross weight): **UK Standard 3-7 Day Delivery -** £4.95; **UK Mainland Next Day Delivery -** £8.95; **Europe (EU) -** £12.95; **Rest of World** - £14.95 (up to 0.5Kg).
Order online for reduced price Postage (from £3.60)
Payment: **We accept all major credit/debit cards. Make cheques/PO's payable to Quasar Electronics Limited.**
Please visit our online shop now for full details of over 1000 electronic kits, projects, modules and publications. Discounts for bulk quantities.

QuasarElectronics.co.uk

Solutions for Home, Education & Industry Since 1993

Official Main Dealer stocking the full range of Kits, Modules, Robots, Instruments and much more...

PIC & ATMEL Programmers

We have a wide range of PIC, ATMEL Arduino and Raspberry Pi projects.

PIC Programmer & Experimenter Board

Great learning tool. Includes programming examples and a reprogrammable 16F627 Flash Microcontroller. Test buttons & LED indicators. Software to compile & program your source code is included. Supply: 12-15Vdc. Pre-assembled and ready to use.
*Order Code: VM111 - **~~£38.88~~ £35.94***

USB PIC Programmer and Tutor Board

The only tutorial project board you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. Programs all the devices a Microchip PICKIT2® can! Use the free Microchip tools for PICKit2™ & MPLAB® IDE environment.
*Order Code: EDU10 - **£46.74***

USB /Serial Port PIC Programmer

Fast programming. Wide range of PICs supported (see website for details). Free Windows software & ICSP header cable. USB or Serial connection. ZIF Socket, leads, PSU not included.
*Kit Order Code: 3149EKT - **~~£49.96~~ £29.95***
*Assembled Order Code: AS3149E - **£44.95***
*Assembled with ZIF socket Order Code: AS3149EZIF - **~~£74.96~~ £49.95***

PICKit™2 USB PIC Programmer Module

Versatile, low cost, PICKit™2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header. USB powered.
*Assembled Order Code: VM203 - **£35.94***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
*Kit Order Code: K8055N - **~~£39.95~~ £22.20***
*Assembled Order Code: VM110N - **£35.94***

2-Channel High Current UHF RC Set

State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 12 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx. Kit includes one Tx (more available separately). 9-15Vdc.
*Kit Order Code: 8157KT - **£44.95***
*Assembled Order Code: AS8157 - **£49.96***

Computer Temperature Data Logger

Serial port 4-ch temperature logger. °C/°F. Continuously log up to 4 sensors located 200m+ from board. Choice of free software applications downloads for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS18S20 sensor.
*Kit Order Code: 3145KT - **~~£19.95~~ £16.97***
*Assembled Order Code: AS3145 - **£22.97***
*Additional DS18S20 Sensors - **£4.96 each***

8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers... Test software & DLL online.
*Assembled Order Code: VM201 - **£130.80***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£15.26***
*Assembled Order Code: AS3179 - **£22.26***

Card Sales & Enquiries 01279 467799

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/5A) in both the forward and reverse directions. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections. PCB: 90x42mm.
*Kit Order Code: 3166KT - **£19.96***
*Assembled Order Code: AS3166 - **£25.96***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our free Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc, 500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

8-Channel RF Remote Control Set

Control 8 onboard relays with included RF remote control unit. Toggle or momentary mode for each output. Up to 50m range. Board Supply: 12Vac, 500mA
*Assembled Order Code: VM118 - **£71.94***

Temperature Monitor & Relay Controller

Computer serial port temperature monitor & relay controller. Accepts up to four Dallas DS18S20 / DS18B20 digital thermometer sensors (1 included). Four relay outputs are independent of the sensors giving flexibility to setup the linkage any way you choose. Commands for reading temperature / controlling relays are simple text strings sent using a simple terminal or coms program (e.g. HyperTerminal) or our free Windows application. Supply: 12Vdc.
*Kit Order Code: 3190KT - **~~£79.96~~ £49.96***
*Assembled Order Code: AS3190 - **£59.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone or 2-wire serial interface for microcontroller or PC communication with simple command set. Suits common anode RGB LED strips, LEDs, incandescent bulbs. 12A total max. Supply: 12Vdc. 69x56x18mm
*Kit Order Code: 8191KT - **£29.95***
*Assembled Order Code: AS8191 - **£29.95***

www.Soundtronics.co.uk

VISIT US AT SYNTHFEST | UK

6/10/2018

60+ analogue synth module kits are available with our matching 5U format front panels, based on the renowned MFOS and YuSynth designs. Kits range from VCO's to 16 step analogue sequencers

A range of 5 single board synths available, each with essential modular synth functions. All built into a compact enclosure, including the popular MFOS Sound Lab Ultimate

Manufactured in-house, our attractive hardwood modular cabinets and desktop cases are a great way to complete your build. Available in maple, oak and walnut timbers.

After a low-cost way of making weird and wonderful sounds, then our lo-fi noise boxes such as the Noise Toaster are a great way to start out

Over 1,000 products to choose from including kits, PCB's and individual components

facebook.com/SoundtronicsUK
www.soundtronics.co.uk

SPECIAL OFFER SPECIAL

EPE EVERYDAY PRACTICAL ELECTRONICS

UK readers you can SAVE 90p on every issue of *EPE*

How would you like to pay £3.75 instead of £4.65 for your copy of *EPE*?

**Well you can – just take out a one year subscription and save 90p an issue, or £10.80 over the year.
You can even save £1.10 an issue if you subscribe for two years – a total saving of £26.40**

Overseas rates also represent exceptional value

You also:

- **Avoid any cover price increase for the duration of your subscription**
- **Get your magazine delivered to your door each month**
- **Ensure your copy, even if the newsagents sell out**

Order by phone, or fax with a credit card, or by post with a cheque or postal order, or buy online from www.epemag.com (go to the Online Shop).

EPE EVERYDAY PRACTICAL ELECTRONICS

SUBSCRIPTION PRICES

Subscriptions for delivery direct to any address in:

UK: 6-months £24.00, 12-months £45.00, 24-months £85.00;

Europe Airmail: 6-months £30.00, 12-months £56.00, 24-months £107.00;

Rest Of The World Airmail: 6-months £37.00, 12-months £70.00, 24-months £135.00.

Cheques or bank drafts (in **£ sterling only**) payable to *Everyday Practical Electronics* and sent to EPE Subs. Dept., Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU.

Tel: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk.

Also via our secure online shop at**: www.epemag.com**.

Subscriptions start with the next available issue. We accept MasterCard or Visa.
(For past issues see the Back Issues page.)

ONLINE SUBSCRIPTIONS

Online subscriptions, for reading the magazine via the Internet, £21.00 for one year, visit **www.epemag.com** for more details.

Free

TEACH-IN 3 CD-ROM WORTH £8.50

with all new, and renewal 12-month hard copy subscriptions on orders placed before August 24 2018

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section, *Practically Speaking,* covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides **over 40 circuit designs** submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

Special Offer

Summer SALE

SPECIAL OFFER

FREE Teach-In 3 CD-ROM with hard copy subscriptions

Announcing our Special Summer Sale!!

EPE Special Offers:

40% off of all PCBs up to and including those in the January 2018 issue
25% off all *EPE* hard copy back issues
25% off all *EPE* back issue 6-month CDROMs
25% off all *EPE* back issue 5-year CDROMs

EPE Subscription Offer:

Subscribe to *EPE* hard copy for 12-months and **receive a free Teach-In 3 CD-ROM (see opposite), normal price £8.50**. If you have an existing subscription then you are welcome to renew early for another year and receive the offer.

Teach-In Bundle:

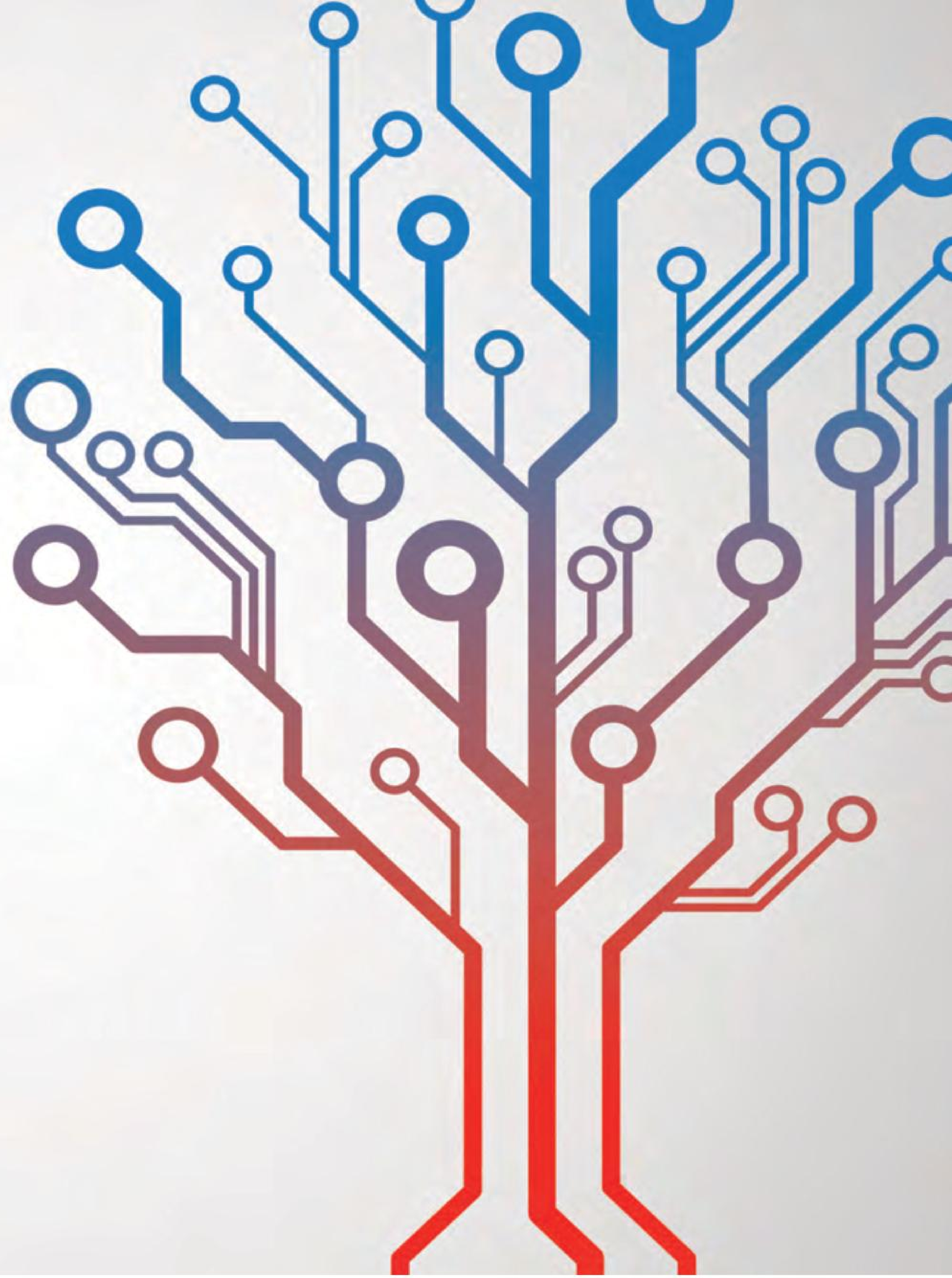
Electronics Teach-In bundle includes
TI CD-ROMs 3, 4 and 5;
Normal price £18.95:
Special offer 25% discount price £14.21

PAYMENT MUST BE RECEIVED BY 24TH AUGUST 2018 WHEN THE OFFER CLOSES

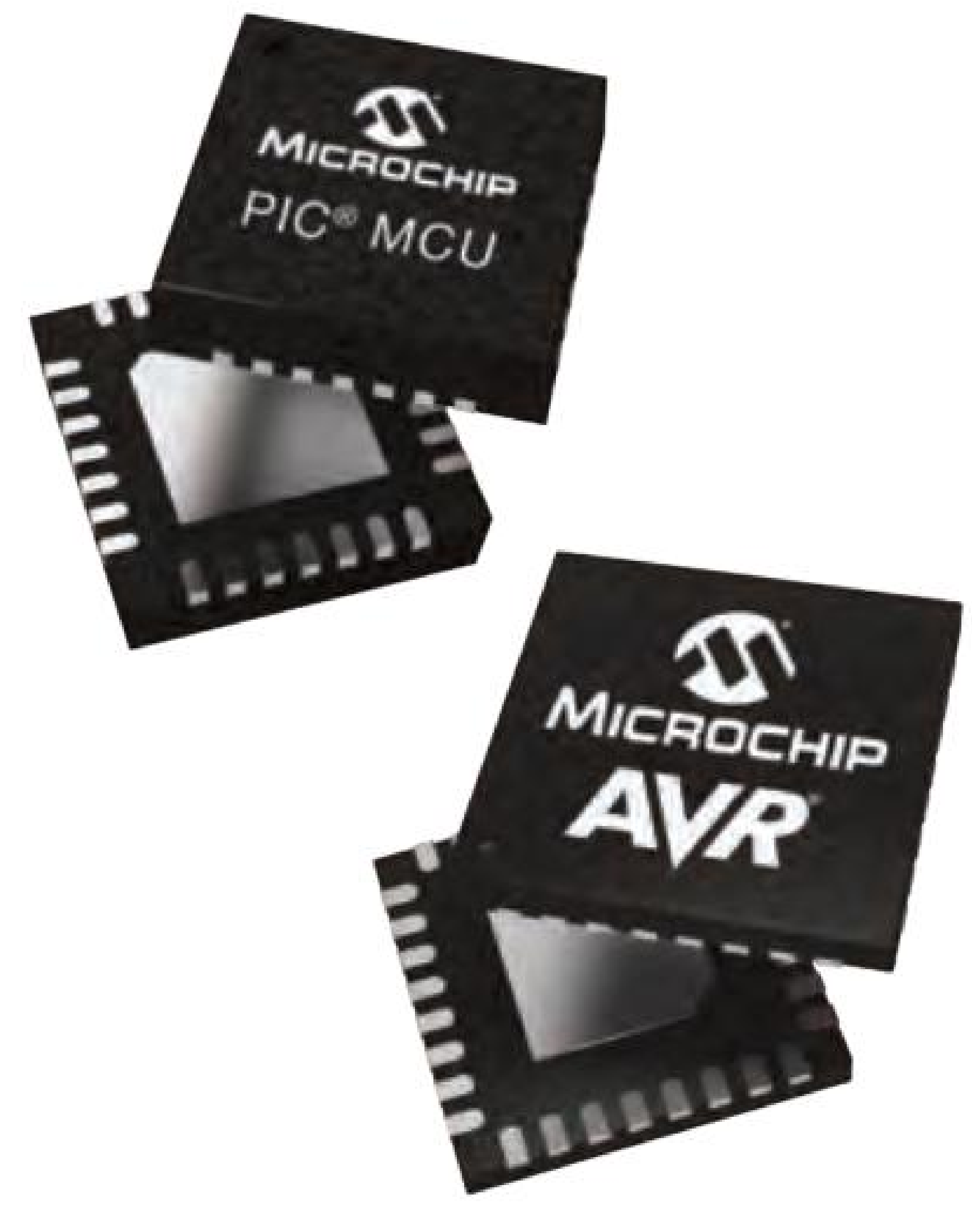
Don't miss out!
Just call 01202 880299 or visit our secure online shop at:
WWW.EPEMAG.COM

PIC® & AVR® MCUs

Together Your Possibilities are Unlimited



You have a desire to make technology smarter, more efficient and accessible to everyone. Microchip has a passion for developing products and tools that make it easier for you to solve your design problems and adapt to future needs. Microchip's portfolio of more than 1,200 8-bit PIC® and AVR® microcontrollers is not only the industry's largest—it incorporates the latest technologies to enhance system performance while reducing power consumption and development time. With 45 years of combined experience developing commercially available and cost-effective MCUs, Microchip is the supplier of choice due to its strong legacy and history in innovation.



Key Features

- Autonomous peripherals
- Low-power performance
- Industry-leading robustness
- Easy development

microchip DIRECT
www.microchipdirect.com

MICROCHIP

www.microchip.com/8bitEU

The Microchip name and logo, the Microchip logo, PIC and AVR are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks are the property of their registered owners.
© 2018 Microchip Technology Inc. All rights reserved. DS30010130A. MEC2116BEng03/18

VOL. 47 No. 9 SEPTEMBER 2018

Editorial Offices:
EVERYDAY PRACTICAL ELECTRONICS
EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk
Website: www.epemag.com
See notes on **Readers' Technical Enquiries** below – we regret technical enquiries cannot be answered over the telephone.

Advertisement Offices:
Everyday Practical Electronics Advertisements
113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299 **Fax:** 01202 843233
Email: stewart.kearn@wimborne.co.uk

Editor: MATT PULZER
Subscriptions: MARILYN GOLDBERG
General Manager: FAY KEARN
Graphic Design: RYAN HAWKINS
Editorial/Admin: 01202 880299
Advertising and Business Manager: STEWART KEARN 01202 880299
On-line Editor: ALAN WINSTANLEY

Publisher: MIKE KENWARD

READERS' TECHNICAL ENQUIRIES
Email: fay.kearn@wimborne.co.uk
We are unable to offer any advice on the use, purchase, repair or modification of commercial equipment or the incorporation or modification of designs published in the magazine. We regret that we cannot provide data or answer queries on articles or projects that are more than five years' old. Letters requiring a personal reply must be accompanied by a stamped self-addressed envelope or a self-addressed envelope and international reply coupons. We are not able to answer technical queries on the phone.

PROJECTS AND CIRCUITS
All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

COMPONENT SUPPLIES
We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers.

We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

ADVERTISEMENTS
Although the proprietors and staff of EVERYDAY PRACTICAL ELECTRONICS take reasonable precautions to protect the interests of readers by ensuring as far as practicable that advertisements are bona fide, the magazine and its publishers cannot give any undertakings in respect of statements or claims made by advertisers, whether these advertisements are printed as part of the magazine, or in inserts.

The Publishers regret that under no circumstances will the magazine accept liability for non-receipt of goods ordered, or for late delivery, or for faults in manufacture.

TRANSMITTERS/BUGS/TELEPHONE EQUIPMENT
We advise readers that certain items of radio transmitting and telephone equipment which may be advertised in our pages cannot be legally used in the UK. Readers should check the law before buying any transmitting or telephone equipment, as a fine, confiscation of equipment and/or imprisonment can result from illegal use or ownership. The laws vary from country to country; readers should check local laws.

EVERYDAY PRACTICAL ELECTRONICS

Introducing the PICMeter

Hard on the heals of Mike Hibbett's excellent 'four-parter' on digital signal processing and the Fast Fourier Transform, this month *PIC n' Mix* heralds the start of Mike O'Keeffe's series on using 16-bit PICs to build a multi-function multimeter – the *EPE PICMeter*. There are two main objectives in this series. First and foremost, learning to use one of Microchip's sophisticated series of 16-bit microcontrollers, and second, to have fun building a flexible and useful circuit.

For those of you who are familiar with 8-bit PICs and are keen to change gear to something a little more powerful, this series will be the answer to your prayers. I am really looking forward to seeing how this project progresses over upcoming issue of *EPE*, and I recommend it to anyone who enjoys the challenges and rewards of PIC-based electronics.

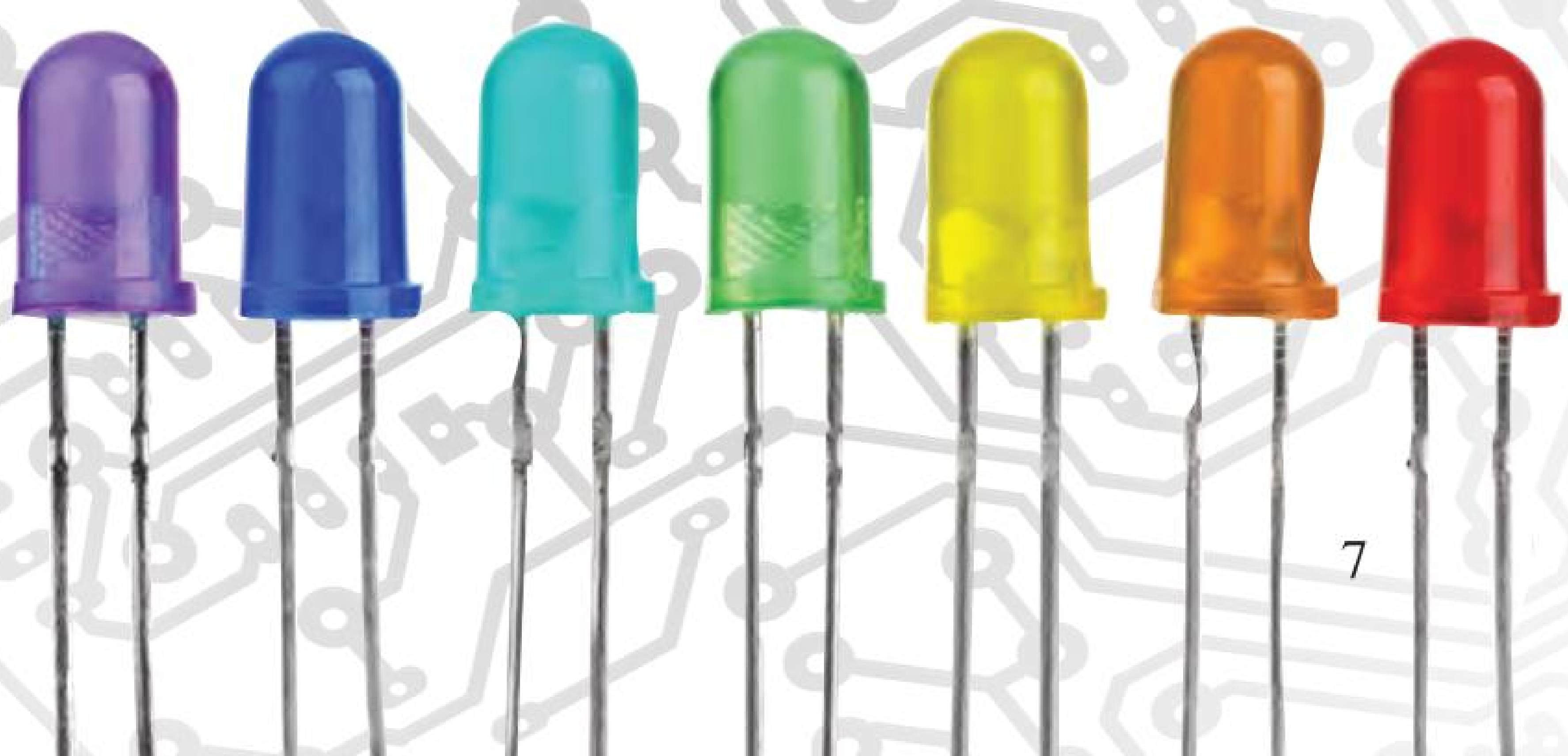
The computer will see you now

In *Three Men in a Boat*, Jerome K Jerome's humorous account of an event-filled Thames odyssey, the narrator recalls how the spur for the trip was a visit to the British Museum, 'to read up the treatment for some slight ailment of which I had a touch – hay fever, I fancy it was'. By the end of his visit he is convinced his ill health ranges from distemper and typhoid to St Vitus's Dance, cholera and diphtheria. He decides, with remarkable stoicism that, 'the only malady I could conclude I had not got was housemaid's knee'.

Such are the pitfalls of self-diagnosis, presumably now made all the more prevalent with every hypochondriac's trusty friend – Google. But, while it's easy to mock those who earnestly search online for the reason behind every ache and pain, the AI industry is close to not just matching but exceeding human diagnostic powers.

A recent report in forbes.com discussed a meeting at the Royal College of Physicians in London, where doctors met to find out how AI might fundamentally change the way they work. Dr Mobasher Butt, a director at digital healthcare startup Babylon Health, announced the results of an exam taken by his company's medically trained AI doctor.

The average pass mark for the MRCGP (Membership of the Royal College of General Practitioners) exam, which trainee GPs take to test their ability to diagnose, has been 72% over the past five years. The AI doctor 'took' the same test and achieved 82%. As with driverless cars, it is still early days and sorting out the complex maze of medico-legal and ethical issues involved with machine diagnosis will doubtless take some time to resolve, but if the result is quicker, more accurate and cheaper health care, then this is to be welcomed.



NEWS

A roundup of the latest Everyday News from the world of electronics

Survival of the toughest and avoiding a licence hangover – report *by Barry Fox*

In the 1970s, all the major Japanese companies built factories in Europe to make TVs, most in the UK because English was the easiest language for the Japanese management. The motivation to build in Europe was simple; the patents filed by Telefunken on the PAL colour system were used to block sale of all TV sets unless they had been made in Europe, and not just assembled from kits of parts.

From TVs to Toughbooks

Almost all those factories closed as the PAL patents expired and the world went digital. But one remains; Panasonic's site near Cardiff in Wales, which opened in 1974. The factory has had to re-invent itself many times to stay viable, explained Kevin Jones, MD Computer Products Solutions, Europe during a press open day held recently to mark the launch of the Panasonic Toughbook FZ-T1 Android handheld. The FZ-T1 is the latest in a line of ruggedised laptops, tablets and mobiles that Panasonic began making in 1995, and has now been assembling in Wales for twenty years.

'It's very tough in business now, and this site has survived because it has changed', said Kevin Jones in a part of the factory which once made surface-mount circuit boards for CRT TVs, and is now Toughbook territory.

At its peak, the Cardiff factory employed 2500 workers on TV manufacture. After TV production ended in 2005, the factory retained a team of engineers to liaise with European broadcasters. Some of the land was sold off for housing. The remaining space has been variously used to make microwave ovens and modules, European games discs for Nintendo consoles, and induction hobs, plus research into fuel cell technology. Since 1998, the site has become the European hub for Toughbook assembly from kits of parts from Panasonic's factories in Japan and Taiwan. Cardiff now serves the whole of Europe and Russia, configuring and customising Toughbooks to suit national and company requirements. The factory also runs a repair service, which collects damaged Toughbooks by courier, mends them and ships them back to their owners, usually within a week. The workforce is now down to 418, but the work is labour-intensive so jobs are reasonably secure.

Panasonic
Google

Panasonic Toughbook FZ-T1 Android handheld

'We are close to our customers', says Kevin Jones, 'so able to react quickly. They tell us what bespoke features they want and we use 3Dprinters here to show them what the factory in Japan can make'.

I was impressed by the clean efficient layout, and noted clever production tricks, like weighing finished packaged boxes to an accuracy of 25 grams – to flag up anything, like a cable or stylus missing, or anything inadvertently added to the contents. The colour of the paperwork that travels with repairs is changed daily so that anything that has been waiting too long is immediately obvious. The new handheld still uses a Micro USB port instead of the newer USB-C design, which can be inserted either way round. 'We don't use the kind of USB Micro sockets that cost 1 cent off the shelf and are good for 1500 insertions and extractions' Kevin Jones explains. 'We need to guarantee 30,000 insertions and extractions and are not yet confident that USB-C can support this'.

Trade uncertainty

Asked how any new trade war tariffs might affect the Cardiff factory and what impact Brexit might have on the pan-European Toughbook operation, Kevin Jones explained: 'Under World Trade rules computers travel globally duty free without tariffs, so that is not an issue. And we don't supply the US market so that is also not an issue; although the pound/dollar exchange rate is now affecting the cost of Microsoft Windows licences. The unknown for us is what may happen at borders, and whether there could be delays after Brexit. We just don't know what will happen.'

Alco-tronics

The electro-chemical technology used by the police for roadside breath testing has now spun down to affordable and deceptively easy-to-use DIY electronics. I checked out the new range of testers from Alcosense Laboratories, a British company based in Maidenhead, Berkshire.

Avoiding a licence hangover – *continued*

Hunter Abbott, AlcoSense's managing director, admits he started the company in 2005 'after a wakeup call'. He had been with a friend to a wedding, and they both responsibly slept at a hotel before driving home at noon the next day. Abbott's friend – who had been similarly 'merry' the night before – was stopped by the police for speeding, got breathalysed and lost his licence for 12 months.

'The problem' he says, 'is that there is no way of telling when the alcohol has cleared your system, and because everyone's different you can't even calculate it.'

DIY breathalyser range

AlcoSense now sells a range of testers, ranging from a twin pack of single-use breathalysers for £2.99, to £249.99 for a top-end device used by professional drivers who cannot afford even the slightest risk of losing their licence.

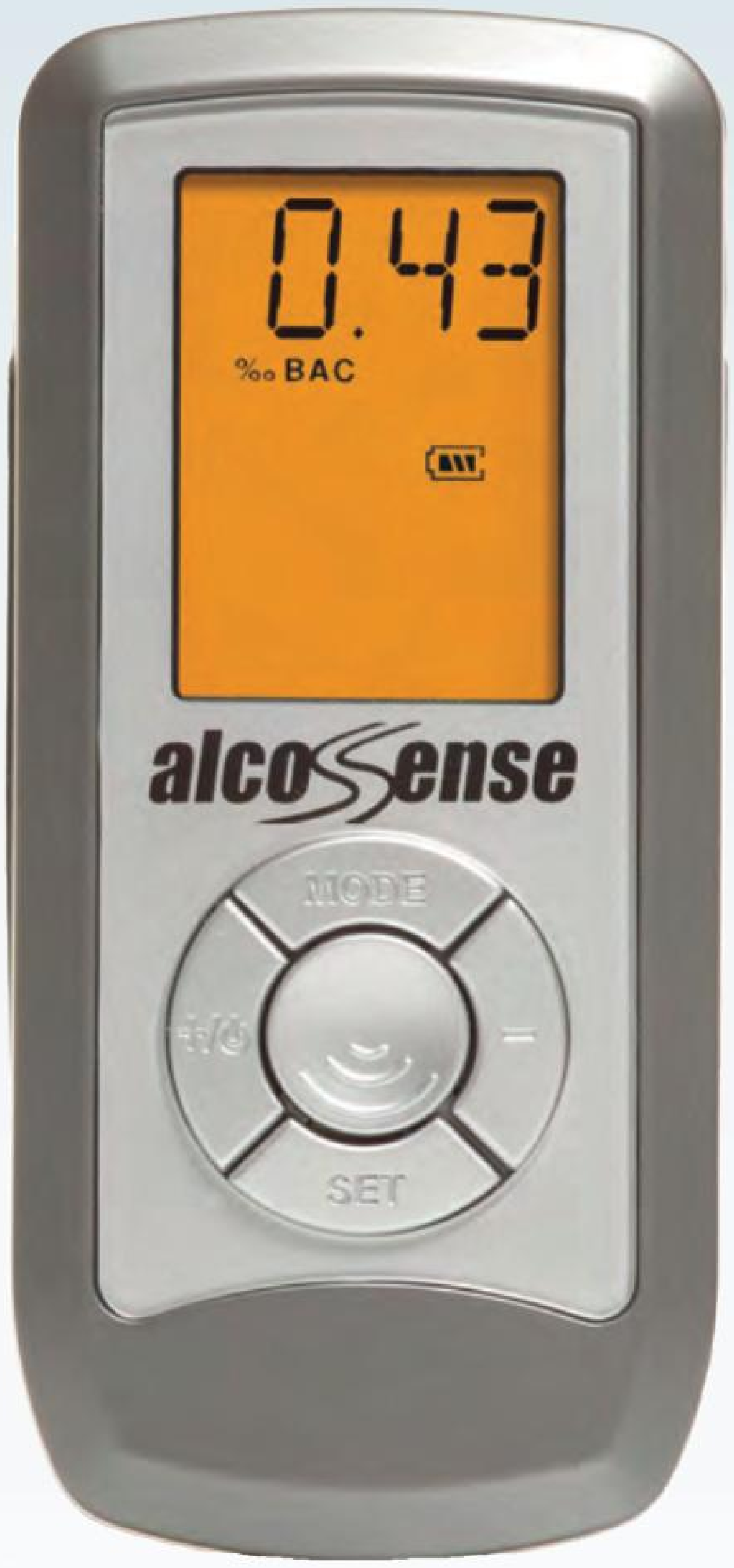
I tried the reusable AlcoSense Excel, which costs just under £100 and is based on a 64mm version of the same platinum fuel cell sensor used by police breathalysers. The cell oxidises the alcohol that comes from the user's breath to generate an electrical current, which represents the concentration of booze in the blood either as 'blood alcohol concentration' (BAC) or milligrams per litre of breath.

What immediately impressed was the work that has gone into making a complex device easy to use, with a detailed but clearly written user manual offering practical advice and setup options for different countries with different drink-drive laws. The sensor reading can be distorted by recently eaten ripe fruit, or mouthwash, blowing too soon after drinking and even loud noise, which the device mistakes for breath puffing.

The sensor can be wrecked by blowing too soon after drinking because there will be very high levels of alcohol in the mouth. Legal drive limits vary even between England and Scotland, so the device needs resetting after a cross-border trip; and the device should be recalibrated every year. All this explains why the police take blood to test after someone has failed a roadside fuel cell breath test.

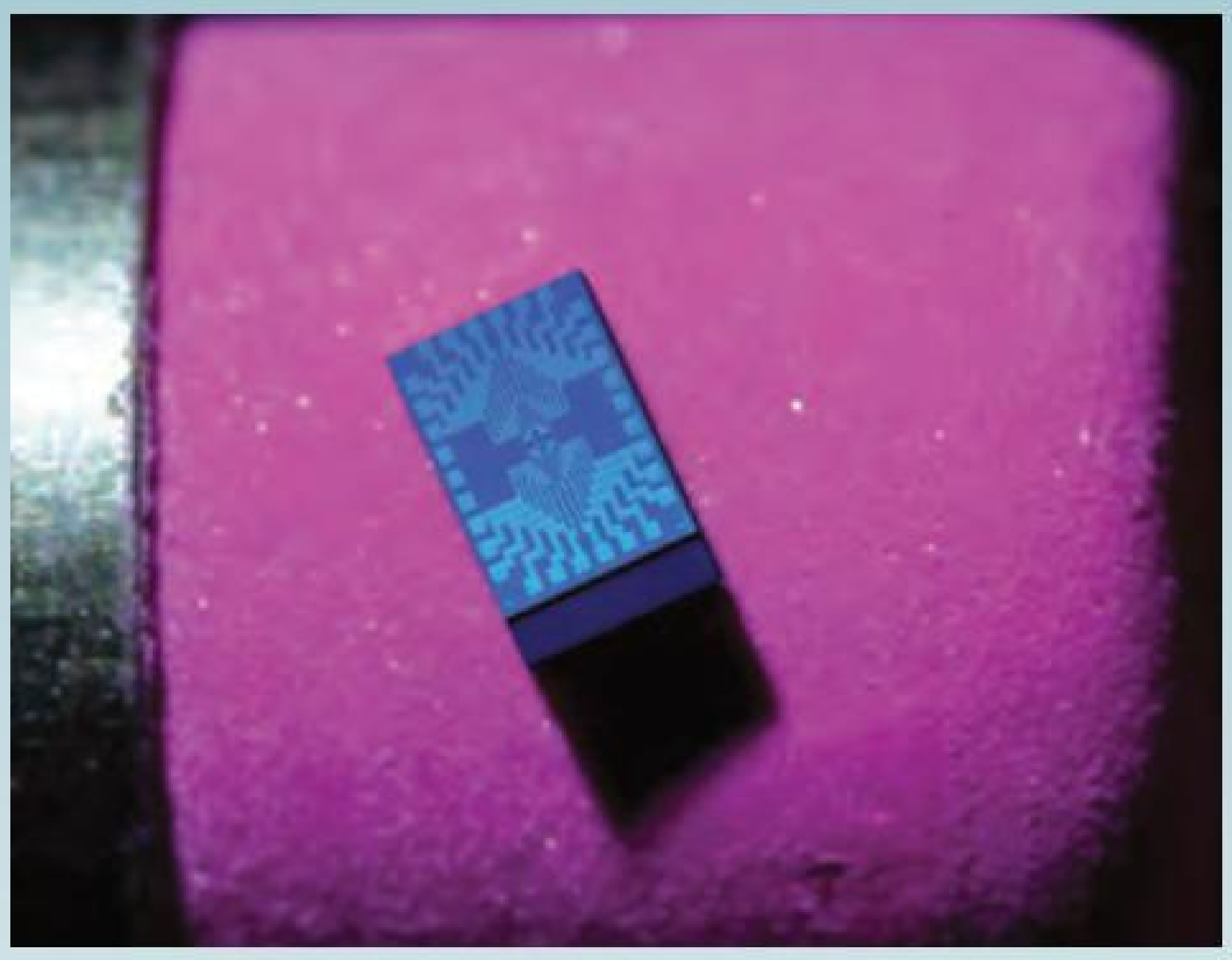
The best time to get a reliable electronic reading is the morning after drinking – which fortunately is just the time when there is the greatest risk of falsely feeling safe to drive.

Further details available at: **https://alcosense.co.uk/products.html**



AlcoSense Elite V2 Breathalyser, available online for around £60

Intel's smallest qubit



Intel's tiny qubit chip (sat on a pencil rubber)

Intel researchers are taking new steps toward quantum computers by testing a tiny new 'spin qubit' chip. The new chip was created in Intel's D1D Fab in Oregon using the same silicon manufacturing techniques that the company has perfected for creating traditional computer chips. It is the tiniest quantum computing chip Intel has made.

The new spin qubit chip runs at the extremely low temperatures required for quantum computing – near absolute zero (0K or –273°C).

The spin qubit chip does not contain transistors – the on/off switches that form the basis of today's computing devices – but qubits (short for 'quantum bits') that can hold a single electron. The behavior of that single electron, which can be in multiple spin states simultaneously, offers vastly greater computing power than today's transistors, and is the basis of quantum computing.

One feature of Intel's tiny new spin qubit chip is especially promising. Its qubits are extraordinarily small – about 50nm across (1,500 qubits could fit across the diameter of a single human hair). This means the design for the new Intel spin qubit chip could be dramatically scaled up. Future quantum computers will contain thousands or even millions of qubits — and will be vastly more powerful than today's fastest supercomputers.

HAMMOND
MANUFACTURING®

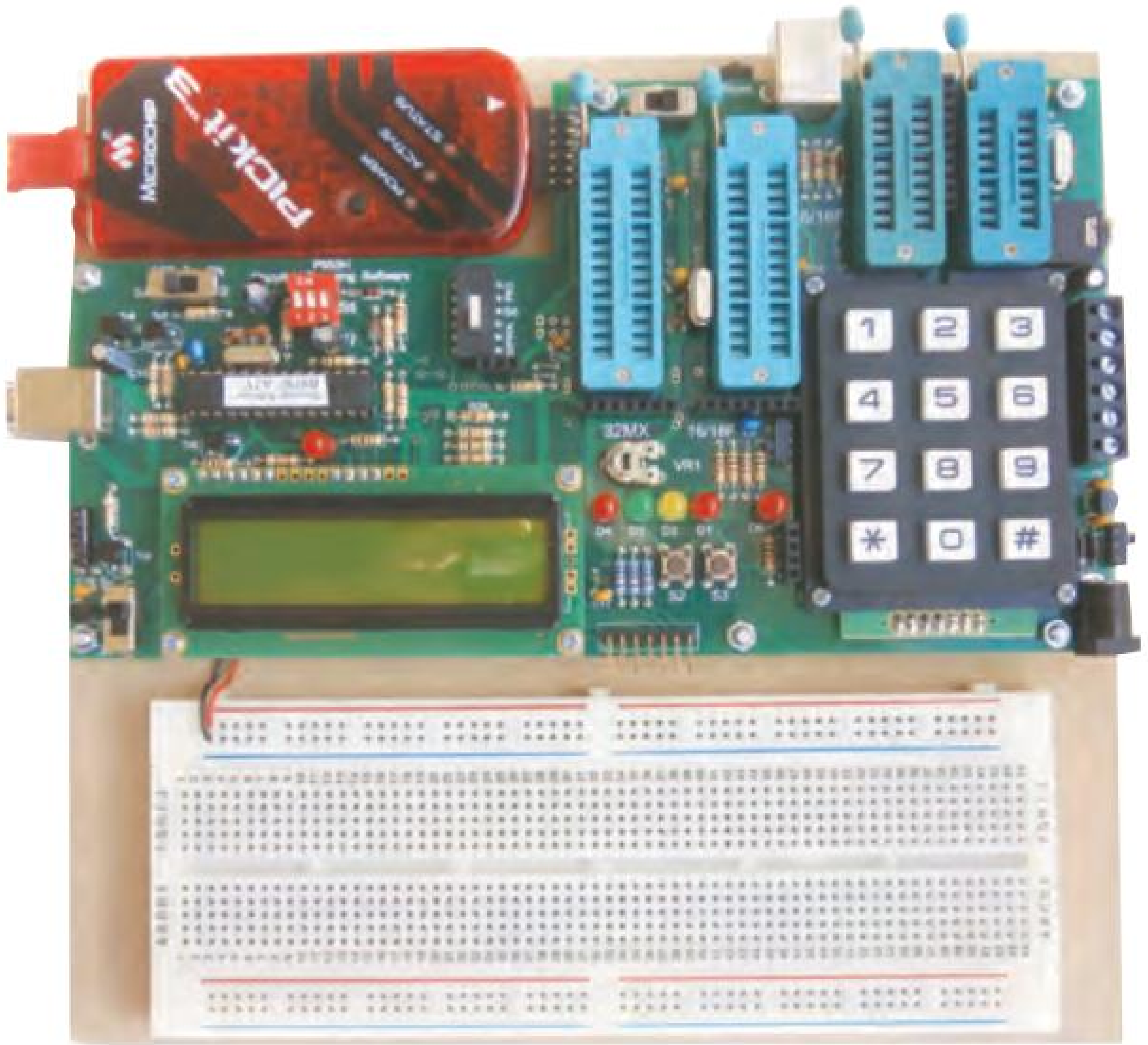
Hand held enclosures standard & waterproof

www.hammondmfg.com/1553.htm
www.hammondmfg.com/1553W.htm

01256 812812
sales@hammond-electronics.co.uk

P955H PIC Training Circuit

by Peter Brunning



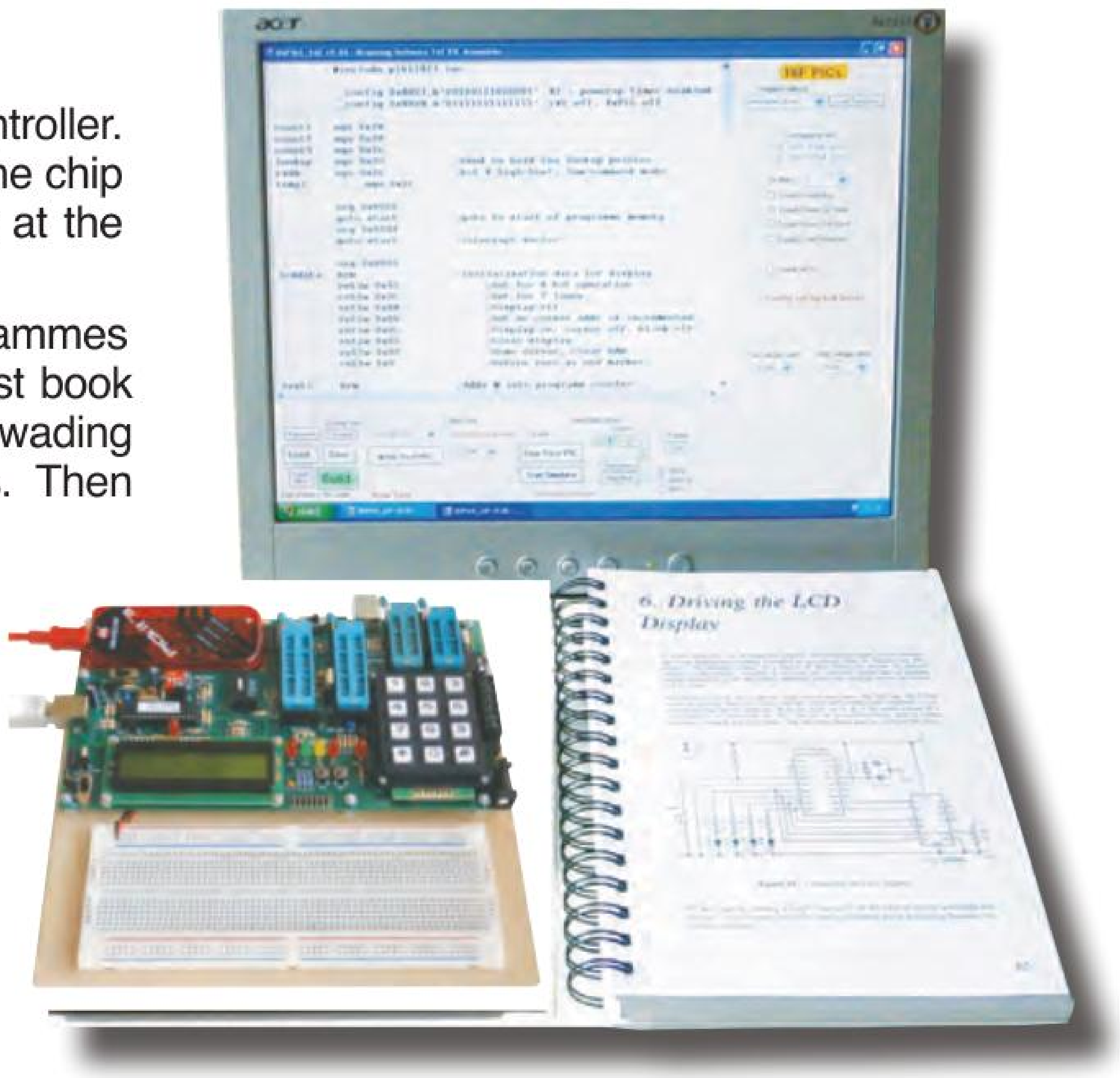
When you are first learning about PICs, whether you are a complete beginner or an experienced programmer, you need an uncomplicated system which allows you to learns about PICs without getting bogged down in system procedure. That is why we created the P955H PIC training circuit and our own PIC assembler. In the first book we learn about PIC programming using the Brunning Software PIC assembler BSPWA but in chapter 3M there is an introduction to the Microchip assembler MPASM X. All our assember text will run in both systems so from there on if you wish you can use MPASM X. Likewise we start by using the on board PIC programmer to write the code into the PIC but if you prefer, plug on a PICkit 3 and use that. The P955H training circuit has the flexibility to be what you need as your learning process advances.

The P955H training circuit has been designed to work with both 32 bit and 8 bit PICs. The idea is to start learning about PICs using assembler with 8 bit PICs. Then learn C with 8 bit PICs, study serial communications using 8 bit PICs, and finally study C programming using 32 bit PICs. It is a simple approach to a subject that has no limit to its ultimate complexity.

The Brunning Software P955H PIC Training Course

We start by learning to use a relatively simple 8 bit PIC microcontroller. We make our connections directly to the input and output pins of the chip and have full control of the internal facilities of the chip. We work at the grass roots level.

The first book teaches absolute beginners to write PIC programmes using assembler which is the natural language of the PIC. The first book starts by assuming you know nothing about PICs but instead of wading into the theory we jump straight in with four easy experiments. Then having gained some experience we study the basic principles of PIC programming, learn about the 8 bit timer, how to drive the alphanumeric liquid crystal display, create a real time clock, experiment with the watchdog timer, sleep mode, beeps and music. Then there are two projects to work through. In the space of 24 experiments two project and 56 exercises we work through from absolute beginner to experienced engineer level using the latest 8 bit PICs (16F and 18F).



The second book introduces the C programming language for 8 bit PICs in very simple terms. The third book Experimenting with Serial Communications teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.

In the fourth book we learn to programme 32 bit MX PICs using fundamental C instructions. Flash the LEDs, study the 16 bit and 32 bit timers, write text to the LCD, and enter numbers using the keypad. This is all quite straightforward as most of the code is the same as already used with the 8 bit PICs. Then life gets more complex as we delve into serial communications with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

The complete P955H training course is £254 including P955H training circuit, 4 books (240 × 170mm 1200 pages total), 6 PIC microcontrollers, PIC assembler and programme text on CD, 2 USB to PC leads, pack of components, and carriage to a UK address. (To programme 32 bit PICs you will need to plug on a PICkit3 which you need to buy from Microchip, Farnell or RS for £43).

Prices start from £170 for the P955H training circuit with books 1 and 2 (240 × 170mm 624 pages total), 2 PIC microcontrollers, PIC assembler and programme text on CD, USB to PC lead, and carriage to UK address. (PICkit3 not needed for this option). You can buy books 3 and 4, USB PIC, 32 bit PIC and components kit as required later. See website for details.

Web site:- www.brunningsoftware.co.uk

Mail order address:

Brunning Software

138 The Street, Little Clacton, Clacton-on-sea,
Essex, CO16 9LS. Tel 01255 862308

TechnoTalk

Time for a rethink?

Mark Nelson

Every time you send an email, download a file from the web or make a phone call using VoIP, your message conforms to a fixed format. This concept only dates back to the late 1830s and the earliest telegraph messages of Cooke and Wheatstone (several years before Samuel Morse in the US)... or does it?

MESSAGE FORMATS, IN THEIR most basic form, are made up of a header or preamble giving origin and destination details, possibly also the subject, and class or priority rating of the message. This is followed by the actual message or data file, and finally by a sign-off or End of Message (EoM) indicator. Formats can and do vary, but this is the essence of the matter and it's both effective and logical. British brains worked this out for the rest of the world! … or so we like to think, but have we got this entirely wrong?

Out of place?

On a visit to the Science Museum in London 18 months ago, I noticed an African talking drum at the entrance to the impressive Information Age gallery. It looked totally out of place among all the surrounding high-techery, leading me to think, 'What's *that* doing here?'. But it was obvious really; it was an early form of telegraph instrument. As Sam Hallas relates at **www.bit.ly/2ImWo5w**, when the explorer and journalist, Stanley – famous for having found Dr Livingstone – was travelling along the Congo river (now the River Zaire), he was mystified to find that villagers already knew he was coming. The talking drum was the means. The drum is made from a tree trunk, hollowed out and shaped. Depending on how you hit it, different notes are produced that can sound like the local language. A means of communicating ideally suited to a country with dense forest, where one cannot see from one village to the next. Another very apt name for the drums is the 'Jungle Telegraph'.

As telegraph systems go, the talking drum predates the electric telegraph by a long chalk. One website traces the origin of the talking drum to the old Oyo empire in south-west Nigeria, which dates back to around 1300. But talking drums were used in several regions of Africa, also in South America, and of course they are still played to this day. 'That's all fine and good,' I hear you say, 'but when are you coming to the point?'

Drumming a 'ringtone'

Right now, in fact. The Bora people of Peru and Colombia can encode complex messages into drumbeats that mimic human speech, and even include a 'ringtone' to announce the start of a message. Earlier this year, *New Scientist* magazine reported how Julien Meyer from the University of Grenoble Alpes had studied 169 messages played by five expert drummers of the Bora people. He discovered that most messages followed a standard message format of four sections: an introduction, the sender's ID, the main message and a sign-off. The drums, known as *manguaré*, are used in pairs, each drum being able to produce two differing notes, making a four-level code system. Playing both drums together acts as a 'ringtone' or 'Call Attention' alert that precedes the message. Suddenly, this 'primitive' communication technology demands to be taken as a relatively sophisticated – and agreeably low-tech – method of telegraphy.

It is also entirely viable. To give just one example, when the British army was defeated by African revolutionaries in Sudan in 1885, this information was broadcast on the same day across thousands of kilometres using the relay systems of African drum telegraphy. Another feature of this 'primitive' method of communication is the use of redundancy (estimated at a ratio of 8:1 on average) as a safeguard against data loss during relay propagation. In fact, the African natives may have been the first to originate the concept of redundancy in communication.

Abandon preconceptions?

This and other technical facets of drum telegraphy are described in a remarkable paper by Zulumathabo Zulu (Google 'African Drum Telegraphy and Indigenous Innovation'). Whereas electrical telegraphic (and computer) systems work by encoding messages using an alphabetic system, the drum telegraph is not constrained in this way and is entirely symbolic. He explains: 'The drum communicators acquired this symbolic system from their erudite ancestors to encode messages before relay. This made it possible for an African in southern Africa to send a drum message to another African in North Africa or elsewhere in the continent. This fact is confirmed by many observers as among the most sophisticated high-speed relay systems that existed along the African equatorial region, wherein a message could be sent over numerous countries and thousands of kilometres without being impeded by the diverse and in some cases mutually unintelligible languages.'

The rest of the paper is way over my head, but its basic thrust left me very impressed. Take a look for yourself if you feel so inclined, and be prepared to cast away your preconceptions of where our method of message data encoding really originated!

Back to the future

Next, to practical matters in everyday electronics. Squeezing greater energy density into the small cells that we use in numerous portable devices means they can deliver more power. 'Cathode materials are always the bottleneck for further improving the energy density of lithium-ion batteries,' says Xiulin Fan, a scientist at the University of Maryland and one of the lead authors of a paper published recently in the scientific journal *Nature Communications*. Research teams at this university, collaborating with the US Department of Energy's Brookhaven National Laboratory and the US Army Research Lab have developed a new cathode material that could triple the energy density of lithium-ion batteries.

Originally, the primary active component of the cathode was cobalt of extremely high purity. Other materials are now being substituted for cobalt, and the latest candidate is a form of iron trifluoride (FeF_3) which has inherently higher capacities than traditional cathode materials by transferring three electrons per molecule rather than just one.

The cathodic material researchers say this research strategy could be applied to other battery technologies as well as to other high-energy conversion materials.

3-Way Fully Adjustable Stereo Active Crossover for Loudspeakers

This *Stereo 3-Way Adjustable Active Crossover* is not only a fantastic tool for loudspeaker design and development, but also it can be integrated into a 2-way or 3-way active (powered) loudspeaker. The crossover points and levels for tweeter, midrange and woofer are fully adjustable with separate controls for each driver.

Part 1

by JOHN CLARKE

Most Hi-Fi loudspeaker systems have passive crossover networks to separate the audio signal into different bands, to suit the tweeters, midrange drivers and woofers. Passive crossovers comprise inductors, capacitors and resistors.

This approach can be simple and economical for a 2-way loudspeaker (ie, with tweeter and woofer) but it can be much more complex and expensive for 3-way loudspeakers (ie, with a midrange driver added), especially if there are big disparities between the efficiencies of the different drivers and if quite steep crossover roll-off slopes are required.

With active crossovers, it's easier to produce steeper roll-off rates and the signal level can be optimised for each driver via its own amplifier.

In more detail, one of the major disadvantages of a passive crossover is that the changeover between the separate frequency bands is usually not very sharp. A typical crossover slope is only 6dB/octave or maybe 12dB/octave, in theory.

In practice, as we shall see, the slope can be much less and that means there is a wide frequency range over which the two drivers will be both producing the same sound frequencies.

That can mean that a woofer will be fed with higher frequencies than it ideally should (eg, above 1kHz) and the tweeter may be fed with lower frequencies (eg, below 1kHz). This means that both drivers are operating outside the regions where they produce the lowest distortion.

Of course, passive crossovers can be designed with steeper roll-offs, but these are more complex and expensive.

Another drawback with passive crossover design is that loudspeakers are not simply resistive, even though their nominal impedance may be 4Ω or 8Ω, for example. Impedance varies with frequency, so an 8Ω loudspeaker may only have an impedance of 8Ω at one frequency.

FEATURES:

- Stereo crossovers
- 3-bands (bass, mid and tweeter) or 2-band use (low pass and tweeter)
- Optional use of the bass output as a subwoofer output in 2-band mode
- Adjustable crossover frequencies
- Individual level controls for each band
- Overall volume control
- Balance control
- Limiter for bass output (optional)

At other frequencies, the impedance can be lower or higher; maybe much higher than the nominal impedance.

So why does the impedance value vary? Because all loudspeakers have inductance.

Loudspeaker impedance also varies because of cone resonances, and in the case of the woofer, due to the air loading on the speaker cone inside the box. These need to be compensated for if the crossover is to work correctly.

(The lowest impedance value for a loudspeaker will typically be just above its cone resonant frequency and will be close to its DC resistance).

This is why you cannot take a passive crossover off the shelf and hope that it will work well with a random selection of drivers mounted in a given enclosure.

Nor can you simply substitute a tweeter or woofer for the original drivers in a loudspeaker system with a passive crossover network – it is not likely to work well!

Solving the problems

By contrast, active crossovers can solve many of the above problems. First, the frequency overlap between two loudspeaker drivers can be minimised by steep roll-off slopes.

Second, the impedance of each driver does not affect the crossover frequency. Nor is there any interaction between the crossover components, as can be the case in passive crossover networks.

Third, the electrical damping of the driving amplifier is not reduced by the impedance of the components in a passive crossover.

This means better damping of woofer cone motion, ie, lower distortion and less boominess.

OK, so active crossovers do have advantages but most designs are not easily adjustable without changing lots of components.

Our new design is fully adjustable for both crossover frequencies and driver signal levels – just twiddle the control knobs!

Low pass, high pass

Before we go any further we should explain some terms which often confuse beginners: low-pass, high-pass and band-pass filters.

Exactly as its name suggests, a low-pass filter is one that allows low frequencies to 'pass' through it, and it blocks higher frequencies. So, a circuit to drive a subwoofer would be called a 'low-pass filter' since it only delivers frequencies below around 200Hz.

Similarly, a high-pass filter is one that allows high frequencies to pass through it, and it blocks low frequencies. The part of a crossover network which feeds a tweeter is said to be a high-pass filter, even though it may consist of only one capacitor.

You would probably realise that as the frequency drops, the impedance of a given capacitor increases, hence blocking the higher frequencies.

If we cascade (ie, connect in series) a high-pass filter with a low-pass filter, the combination will pass a band of frequencies and we then refer to it as a 'band-pass filter.' We use a band-pass filter for the midrange output in this active crossover circuit.

Other points you need to know about high and low-pass filters are the so-called 'cut-off frequency' and the 'filter slope roll-off'.

Typical filter slopes are specified in dB/octave where the dB (decibel) term is the attenuation. Typical slopes are –6dB/octave (quite gradual), –12dB/octave, –18dB/octave and –24dB/octave (quite steep for a crossover network).

The filter slope operates on frequencies after the cut-off frequency. The cut-off frequency is where the signal output is –3dB down on the normal level.

For example, in a low-pass filter we might have a cut-off frequency of 1kHz (ie, –3dB point) and at slightly above that frequency, the slope will be –12dB/octave. And for the filters described here, this means that the response at 2kHz (ie, one octave above) will be –12dB and at 4kHz it will be –24dB.

Two or three filter bands?

Fig.1(a) shows the three filter bands available with our new *Active Crossover*. While it may not be immediately apparent, this involves two crossover points and no fewer than four filters.

Starting from the left-hand side, we have a low-pass filter for the bass frequencies and it 'crosses over' to a high-pass filter for the midrange frequencies. Further up the audio spectrum, we have another low-pass filter which blocks out higher frequencies and then it 'crosses over' to another high-pass filter which handles the frequencies fed to the tweeter.

Note that when we shift the low crossover frequency, we are simultaneously changing the cut-off frequencies of the respective low-pass and high-pass filters – they are ganged together.

Similarly, when we shift the high crossover frequency, we simultaneously change the cut-off frequencies for the midrange low-pass and upper high-pass filters.

Fig.1(a) shows the new *Active Crossover* used in a 3-way configuration, with bass (woofer), midrange driver and tweeters.

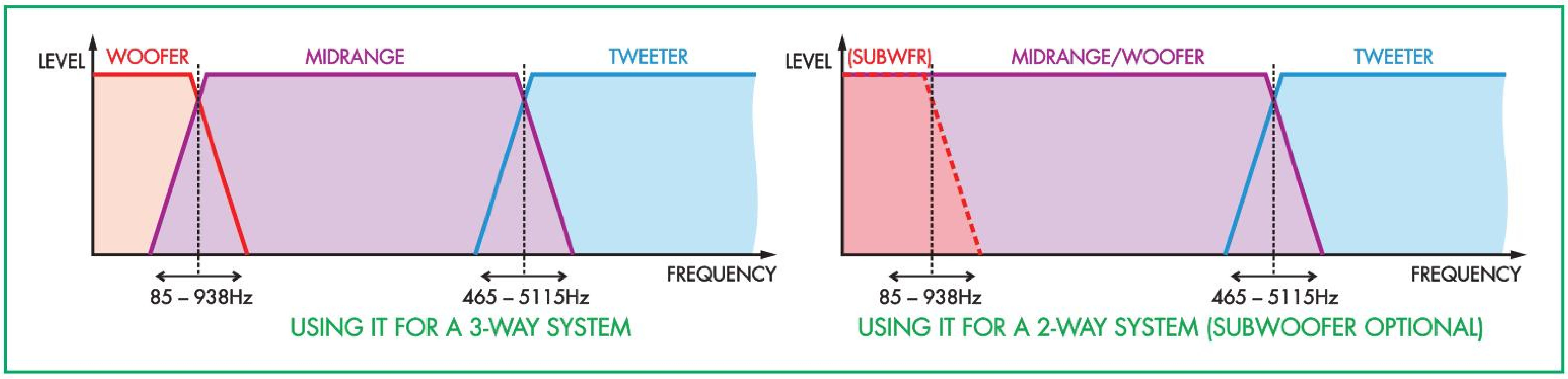


Fig.1: the stereo audio signal is split into three separate stereo signals covering different frequency ranges, to suit the woofers, mid-range drivers and tweeters. For a two-way system, the third signal can optionally be used for subwoofer(s).

But Fig.1(b) shows that it could be used in an alternative configuration as a 2-way system with a midrange/woofer and a tweeter, together with an optional subwoofer. The circuitry remains the same, but the way you connect it is a little different. We will talk about that later.

Calculating R and C

If you wish to do some calculations of responses for these filters, an excellent website is available. This calculates the filter responses for the Sallen-Key configuration and shows plots and filter Q for values of R and C.

For the low-pass filter, C1 is the capacitor that needs to be twice in value to C2. R2 is double the resistance of R1 in the high-pass filter.

For a cut-off of 1kHz (f_c), C = 22nF (44nF for twice the value) and R = 5.11543kΩ (10.23086kΩ for twice the value).

For the high-pass filter see: **http://bit.ly/2KHq53h**

For the low-pass filter see: **http://bit.ly/2jB25Tc**

Block Diagram

Fig.2 shows the block diagram for the *3-Way Adjustable Active Crossover*. Only the left channel is shown; the right channel is identical.

It actually comprises four low-pass and four high-pass filters. Hmm, we just mentioned that only four filters were needed to produce the three bands shown in Fig.1. Why are there now eight filters involved? Patience – all will be revealed!

The left and right channel inputs are fed to a stereo volume control (VR1a and VR1b) and the signal is then buffered with op amps IC1a and IC1b and their outputs connect to the balance control, VR2.

After further buffering by op amps 1C2a and IC2b (for the right channel), the signal is passed to two adjustable high-pass filters involving IC4 and IC5 (signal path in green) and also fed to two adjustable low-pass filters involving IC3 (signal path in blue).

The signal from the high-pass filters is fed to the tweeter level control and then to the tweeter output, CON2a. The signal from the low-pass filters is fed to a second pair of adjustable high-pass filters involving IC7 and IC8 and to a second pair of adjustable low-pass filters involving IC6.

The output from the second pair of high-pass filters is fed to the midrange level control and then to the midrange output, CON3a.

The output from the second pair of low-pass filters is fed to the bass level control (signal path in red) and then goes via the bass limiter (can be switched in or out) to the woofer (or subwoofer) output, CON3b.

Why do we need a bass limiter? Because we envision that in some applications, the bass output will need to be boosted substantially and that could lead to overload of the woofer or woofer driver amplifier on loud passages.

The bass limiter will prevent this while having negligible effect on the signal at other times.

Two-way configuration

As noted above, this *Active Crossover* can also be built as a 2-way system with an optional subwoofer output. In that case, you would have a tweeter output (CON2a), the midrange/woofer output (CON2b) and the subwoofer output (CON3b). The circuitry for IC6, IC7 and IC8 could then be omitted.

So now let us explain why we need eight active filters in each channel rather than four.

Fig.3 a, and b show the basic circuits for the low-pass and high-filters used in our *Active Crossover*.

Let's talk about the low-pass filter first, as shown in Fig.3(a). This

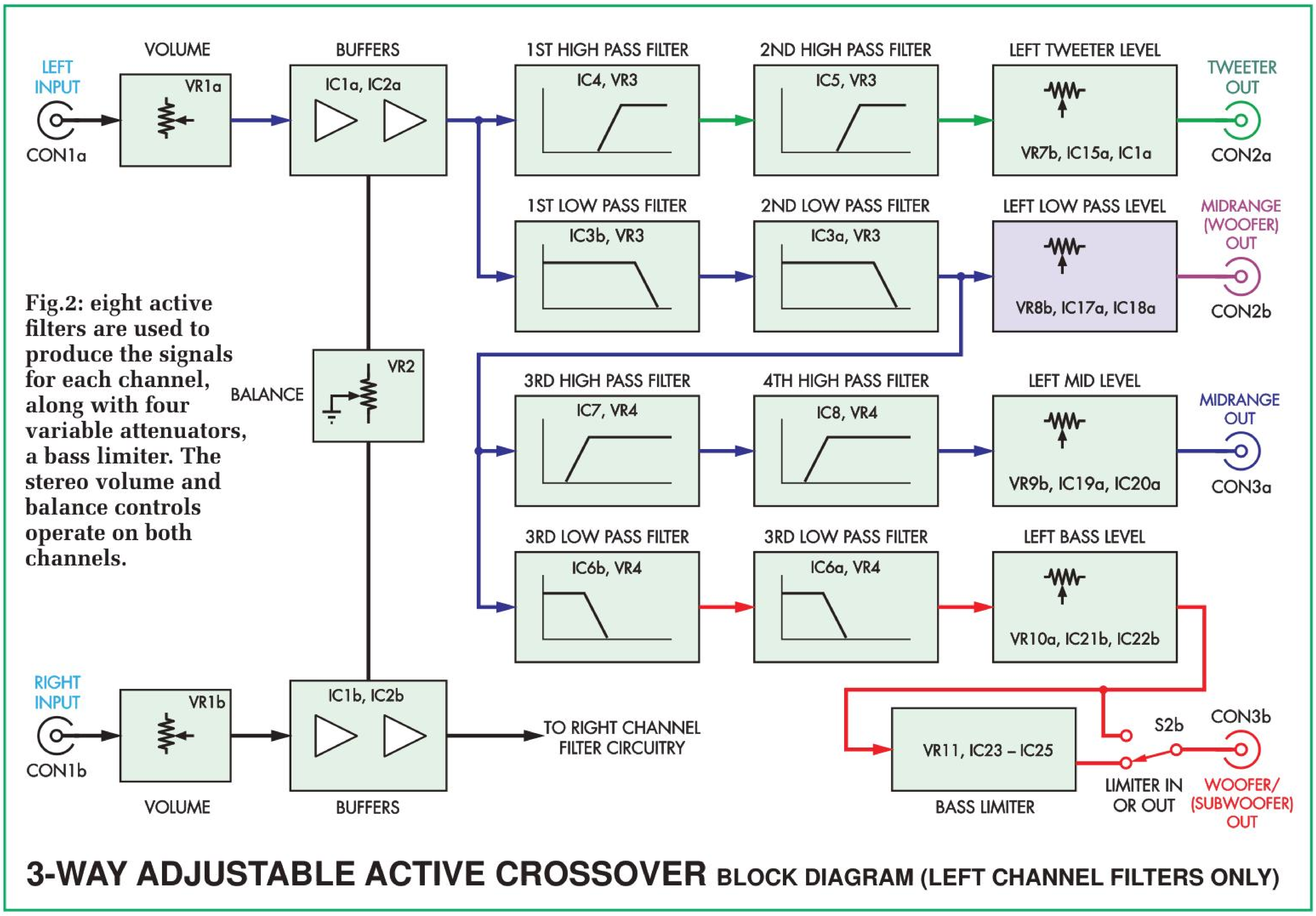


Fig.2: eight active filters are used to produce the signals for each channel, along with four variable attenuators, a bass limiter. The stereo volume and balance controls operate on both channels.

LEFT INPUT
CON1a
VOLUME
VR1a
BUFFERS
IC1a, IC2a
1ST HIGH PASS FILTER
IC4, VR3
2ND HIGH PASS FILTER
IC5, VR3
LEFT TWEETER LEVEL
VR7b, IC15a, IC1a
TWEETER OUT
CON2a
1ST LOW PASS FILTER
IC3b, VR3
2ND LOW PASS FILTER
IC3a, VR3
LEFT LOW PASS LEVEL
VR8b, IC17a, IC18a
MIDRANGE (WOOFER) OUT
CON2b
BALANCE
VR2
3RD HIGH PASS FILTER
IC7, VR4
4TH HIGH PASS FILTER
IC8, VR4
LEFT MID LEVEL
VR9b, IC19a, IC20a
MIDRANGE OUT
CON3a
3RD LOW PASS FILTER
IC6b, VR4
3RD LOW PASS FILTER
IC6a, VR4
LEFT BASS LEVEL
VR10a, IC21b, IC22b
RIGHT INPUT
CON1b
VR1b
VOLUME
IC1b, IC2b
BUFFERS
TO RIGHT CHANNEL FILTER CIRCUITRY
VR11, IC23 – IC25
BASS LIMITER
S2b
LIMITER IN OR OUT
CON3b
WOOFER/ (SUBWOOFER) OUT
3-WAY ADJUSTABLE ACTIVE CROSSOVER BLOCK DIAGRAM (LEFT CHANNEL FILTERS ONLY)

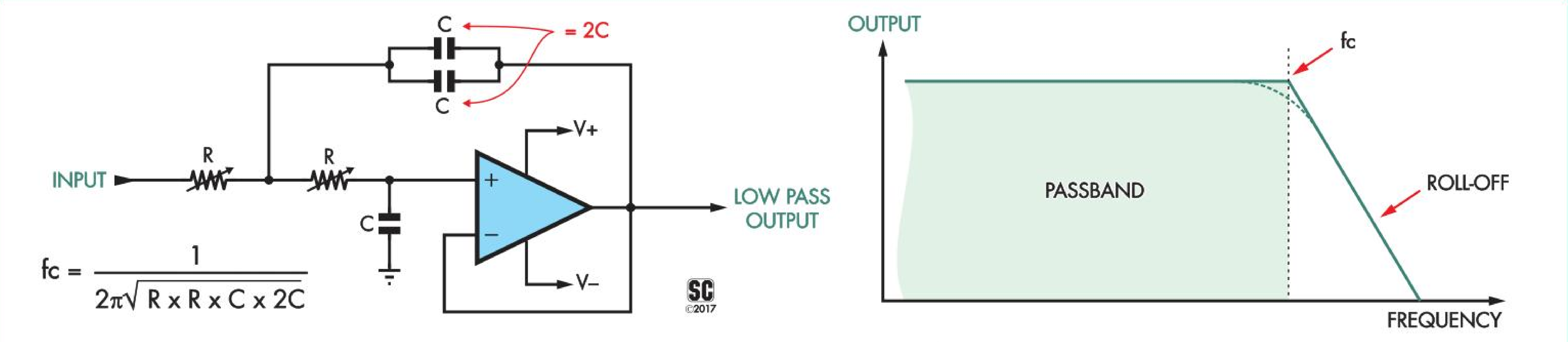


Fig.3(a): this is the configuration of each second-order low-pass filter, which is known as a Sallen-Key type. Its expected frequency response is shown at right. Note that the variable resistances required are of the same value.

consists of a single op amp together with two identical (adjustable) resistors R and two capacitors, C and 2C. (2C is actually two identical capacitors in parallel). The op amp is connected as a unity-gain buffer and because it uses two RC networks, it is a second-order filter which gives a roll-off slope of 12dB/octave.

The basic design is referred to as a 'Sallen-Key filter' (after RP Sallen and EL Key of MIT Lincoln Laboratory in 1955).

The graph to the right of the circuit shows the roll-off slope beyond the cut-off frequency (f_C). The passband region refers to the frequencies below f_C where the signal level is mostly unaffected by the filter.

For this particular circuit, the filter has a Q of 0.7071 and has a Butterworth response. The Q value means that the frequency response below f_C remains as flat as possible rather than with any amplitude ripple or peaking.

The equation for calculating the f_C for the filter is shown (in Fig.3(a)) though this calculation only applies to a Butterworth filter.

High-pass filter

By swapping the resistors and capacitors in the circuit of Fig.3(a), we can obtain a high-pass filter, as shown in Fig.3(b).

Once again, this is arranged to have a Butterworth response with a Q=0.7071 but instead of having capacitors with values of C and 2C, we have resistors of 2R, between the non-inverting input of the op amp and ground, and R at the output of the op amp.

Both these resistive elements are adjustable using potentiometers and that presents a big problem because our *Active Crossover* uses an 8-gang potentiometer for each crossover output; each potentiometer element needs to have the same value, eg, 10kΩ.

To solve that problem, we use an extra op amp, as shown in Fig.3(c). The second op amp is connected as a unity gain buffer and is driven from a voltage divider connected to the output of the first op amp, to drive the bottom end of the potentiometer (R).

This resistor now has half the signal current through it and so acts as though it has a value of 2R – which is what we want.

So that shows the configuration of all the low-pass and high-pass filters in the circuit, but it does not explain why we using four of each.

The reason is that the circuits of Fig.3 are second-order filters and their filter slopes are equal to 12dB/octave, which is not particularly steep – we want twice that: 24dB/octave. So we use identical cascaded low-pass and high-pass filters to get the desired result.

We simulated the filter circuits using LTspice to obtain the actual responses for the filters.

Fig.4 shows the results for the low-pass filter when the cut-off frequency is 1kHz. The response for the single-stage Butterworth filter is 3dB down at the cut-off frequency. At 10kHz (one decade away) the response is down by 40dB, as expected. That's a 40dB per decade (or 12dB/octave) roll-off.

When the two filters are cascaded, we get a response that is referred to as 'Butterworth squared' (also called a Linkwitz-Riley) filter. The combined filter Q is 0.5; obtained by multiplying the Q (0.7071) of each Butterworth stage together. The cascaded filter response is 6dB down at f_C and 80dB down at 10kHz. Putting it another way, the combined filter slope, beyond f_C, is 24dB/octave.

Similar results for the low-pass filter are also shown in Fig.4; –3dB down at 1kHz for the single stage and 6dB down at 1kHz for the cascaded filters. At 100Hz (one decade away), response is 40dB down for the single-stage filter and 80dB down for the cascaded filter.

We use the Linkwitz-Riley filters because when both the low and high-pass filters are summed, acoustically the response is flat.

Using the Linkwitz-Riley filters means that there are no dips or peaks in the frequency response across the crossover frequency region.

For more information on Linkwitz-Riley filters, see: **https://en.wikipedia.org/wiki/Linkwitz–Riley_filter**

The left and right channels have separate frequency adjustments. Ideally, both left and right channels should be able to be adjusted together for the same crossover frequencies. However,

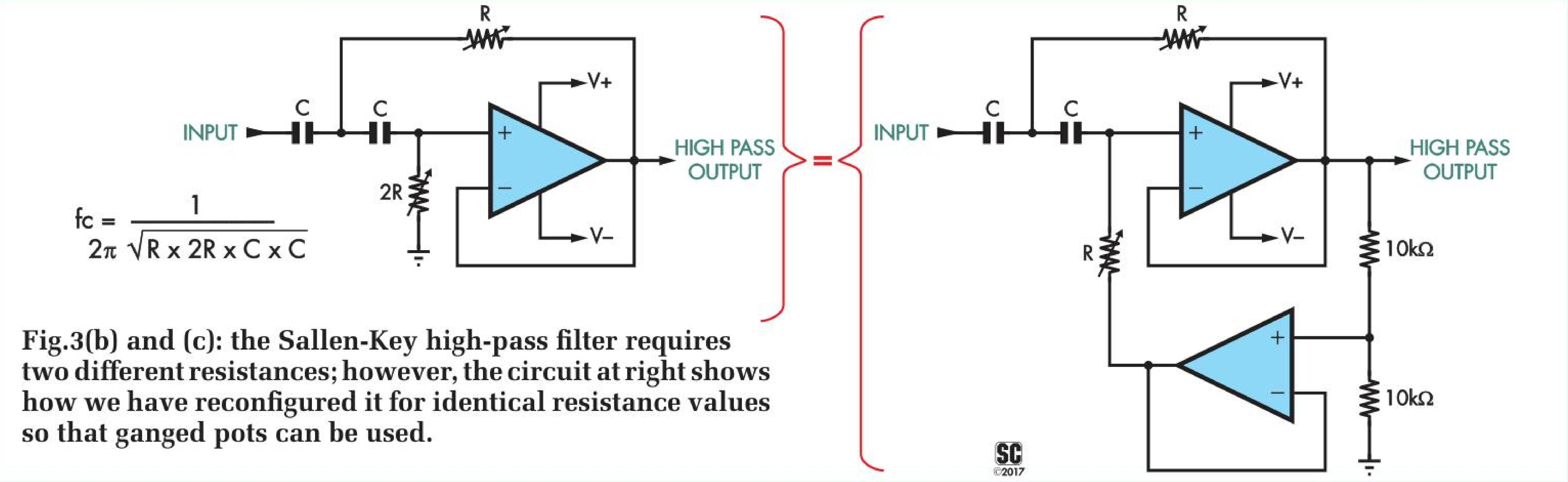


Fig.3(b) and (c): the Sallen-Key high-pass filter requires two different resistances; however, the circuit at right shows how we have reconfigured it for identical resistance values so that ganged pots can be used.

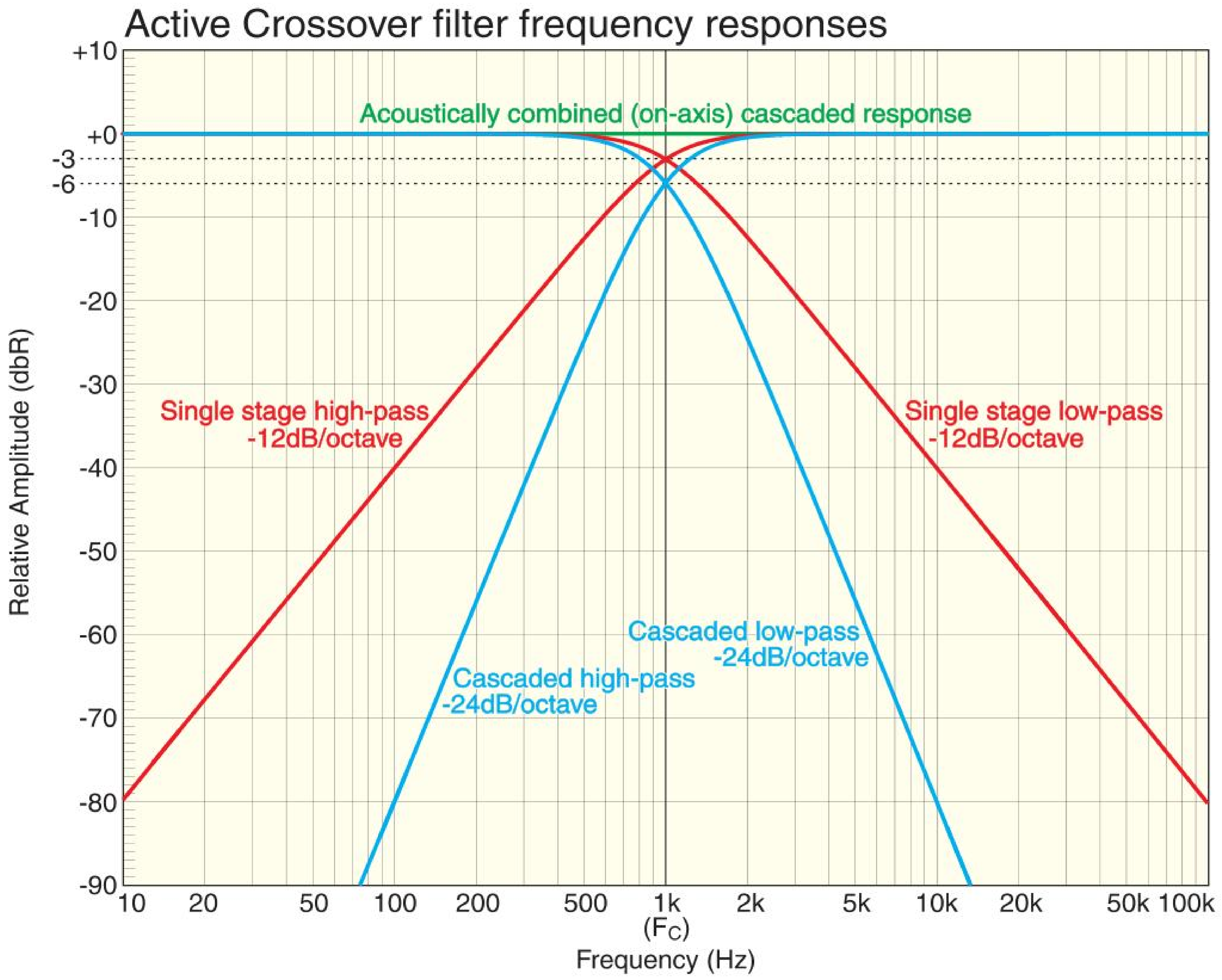


Fig.4: the simulated response of a single pair of Sallen-Key low-pass/high-pass filters with a corner frequency of 1kHz (red) and the cascaded pairs of Sallen-Key filters (red), known as a Linkwitz-Riley arrangement. The flat green line shows the overall response when the signals are acoustically summed.

we were not able to do this easily and we shall see why later.

Main circuit

The main circuit of the *Active Crossover* is shown in Fig.5 and again, this only shows the left channel. Just so you can recognise the various low-pass and high-pass filters, dual op amps IC4 and IC5 are the cascaded first and second high-pass filters, while dual op amp IC3b and IC3a are the cascaded first and second low-pass filters. All op amps in the circuit are LM833s for very low noise and distortion.

Similarly, dual op amps IC7 and IC8 are the cascaded third and fourth second high-pass filters, while dual op amp IC6b and IC6a are the cascaded third and fourth low-pass filters.

Also note that all the potentiometer elements for the filters of IC3, IC4 and IC5 are part of the same 8-ganged potentiometer, VR3. Similarly, all the potentiometer elements for the filters of IC6, IC7 and IC8 are part of the same 8-ganged potentiometer, VR4.

However, that means that this *Active Crossover* is not able to simultaneously adjust the crossover frequencies in both channels; each channel must be done separately. If we wanted to do both channels simultaneously, we would need 16-element pots and that is simply not practical.

However, the level adjustments for each channel output are made using dual ganged pots, so these are done simultaneously.

Now let's track the signal through the crossover circuitry. The input signal is applied to an RF suppression network comprising ferrite bead L1, a 100Ω stopper resistor and a 10pF capacitor. The signal is then coupled to the volume control VR1a via a 22µF non-polarised capacitor.

The signal from the wiper of VR1is buffered by IC1a and its output is connected to one side of the balance control, VR2.

The balance control has a limited range of action and it works as follows. When centred, there is an equal loss in signal level for both channels that amounts to –1.42dB.

When the pot is rotated off centre, more signal is shunted to ground in one channel than in the other channel.

When the balance pot is rotated fully in one direction, it causes a loss of 8.3dB in one channel and a slight increase in the other. So there is an overall 8.9dB change in level between one channel and the other.

Following the balance control, the signal is again buffered by IC2a and then fed to the first high-pass and first low-pass filters involving IC4 and IC3, respectively.

So the signal progresses through the first and second high-pass filters of IC4 and IC5 and also to the first and second low-pass filters of IC3b and IC3a.

Then the respective tweeter and midrange signals are fed to the respective level controls, involving VR7b and VR8b.

These are Baxandall circuits which give a logarithmic response when using a linear potentiometer. This is highly desirable since we want to use linear dual ganged pots and these have far better matching and tracking between channels than logarithmic taper pots.

Two op amps are involved for each level control. The tweeter control, VR7b, involves op amp IC15a, configured as a buffer, and IC16a, an inverting op with a gain of 4.5.

Hence the overall gain range of the circuit is from unity to 4.5, which is more than adequate for this application. Another advantage of this Baxandall level control is that it reduces noise at the lower gain settings.

Further filter stages

The output of the second low-pass filter involving IC3a is also fed to the third and fourth high-pass filters involving op amps IC7 and IC8 and also to the third and fourth low-pass filters involving IC6b and IC6a.

The output of the fourth high-pass filter IC8a is fed to the midrange level control VR9b involving op amps IC19a and IC20a.

Finally, the output of the fourth low-pass filter IC6a is fed to the bass level control VR10a involving op amps IC21a and IC22a.

However, the bass level control can also be fed to the bass limiter, which can be switched in or out using switch S2.

Laser
Why tolerate when you can automate?
X-10 Home Automation
KATS AV transmission and IR control system
Barix Ethernet based MP3, communications and control systems
www.laser.com
Integrators, Installers, Trade and Retail customers welcome
C-Bus Shop
C-Bus and C-Bus Wireless
www.cbus-shop.com
Laser Business Systems Ltd
Tel: +44 (0) 20 8441 9788
Fax: +44 (0) 20 8449 0430
Email: info@laser.com
16 Garthland Drive, EN5 3BB

Parts List – Three-Way Active Crossover

1 main PCB, available from the *EPE PCB Service*, coded 01108171, 284 x 77.5mm
1 front panel PCB, available from the *EPE PCB Service,* coded 01108172, 296 x 43mm
1 rear panel PCB, available from the *EPE PCB Service,* coded 01108173, 296x 43mm
1 16VAC 1A (or higher current) plugpack
2 DPDT PCB-mount push button switches (S1,S2)
2 knobs to suit push button switches S1 and S2
1 two-way vertical stacked PCB-mount RCA socket (CON1)
2 four-way vertical stacked PCB-mount RCA sockets (CON2,CON3)
4 knobs to suit VR3-VR6
6 knobs to suit VR1,VR2,VR7-VR10)
2 TO-220 heatsinks, 19 x 19 x 9.5mm
1 PCB-mount 2.5mm DC power socket (CON4)
1 2.5mm DC line plug
1 3-way PCB-mount screw terminals with 5.08mm spacing (CON5)
2 5mm ferrite suppression beads (L1,L2)
2 ORP12 (or equivalent) LDRs
1 50mm length of 6mm-diameter black heatshrink tubing
1 set of black acrylic case pieces (SC4403)
8 16mm-long M3 tapped spacers
4 9mm-long M3 tapped nylon spacers
4 M3 x 32mm machine screws
4 M3 x 5mm black machine screws
2 M3 x 6mm screws and nuts
4 self-adhesive or screw-on rubber feet

Semiconductors
25 LM833D SOIC (SMD) dual op amps (IC1-IC25)
1 7815 +15V three-terminal regulator (REG1)
1 7915 -15V three-terminal regulator (REG2)
2 1N4148 diodes (D1,D2)
2 1N5819 Schottky diode (D3,D4)
1 W04 1.2A bridge rectifier (BR1)
2 5mm 7500mcd green LEDs (LED1,LED2)
1 3mm blue LED (LED3)

Capacitors
2 470µF 25V PC electrolytic
1 100µF 16V PC electrolytic
10 22µF NP 50V PC electrolytic
12 10µF 35V (or greater) PC electrolytic
20 120nF 63V or 100V MKT polyester
25 100nF X7R 50V SMD (1206) ceramic
20 22nF 63V or 100V MKT polyester
11 100pF X7R 50V SMD (1206) ceramic
2 100pF 50V ceramic

Reproduced by arrangement
with SILICON CHIP
magazine 2018.
www.siliconchip.com.au

Resistors (0.25W, 1%, through-hole or 1206 SMD as specified)
2 100kΩ
1 5.6kΩ
2 620Ω
7 100kΩ SMD
8 2.2kΩ
8 150Ω
8 22kΩ
2 2.2kΩ SMD
2 100Ω
2 10kΩ
2 1kΩ
26 10kΩ SMD
38 1kΩ SMD

Potentiometers and trimpots
1 10kΩ log dual 9mm potentiometer (VR1)
1 10kΩ linear single 9mm potentiometer (VR2)
4 10kΩ linear 8-gang 9mm potentiometers, Bourns PTD9081015FB103 (VR3-VR6)
4 10kΩ linear dual 9mm potentiometers (VR7-VR10)
1 5kΩ 25-turn top adjust 3296W style trimpot (VR11)

Limiter circuit operation

The limiter circuit is shown in Fig.6 and it acts on the signals from both channels, left and right.

In essence, the bass signal from each channel (left from IC22a; right from IC22b) is fed to a passive attenuator comprising a 10kΩ resistor, a 100kΩ resistor to ground and a paralleled light-dependent resistor (LDR). LDR1 is used for the left channel and LDR2 for the right channel.

Normally, the LDR resistance will be very high and the reduction in signal level will be less than 1dB. Op amp IC23b buffers the signal from LDR1, while IC23a buffers the right-channel signal from LDR2.

Each LDR is located next to an LED and both are encased in a light-proof housing (made of heatshrink tubing). So light from LED1 can reduce the resistance of LDR1, and LED2 does the same for LDR2. Both LEDs are driven with the same current so that the signal level in both channels is reduced by the same amount.

The drive signals to LED1 and LED2 are derived by dual op amps IC24 and IC25. The bass signals from IC23a and IC23b connect to the inverting inputs of IC24a and IC24b via 1kΩ resistors which mix the signals from both channels.

These amplifiers have a gain of 100 by virtue of their 1kΩ input and the 100kΩ feedback resistors.

The amplifiers also have their non-inverting inputs connected to separate voltage references formed using a resistive divider across the ±15V supply.

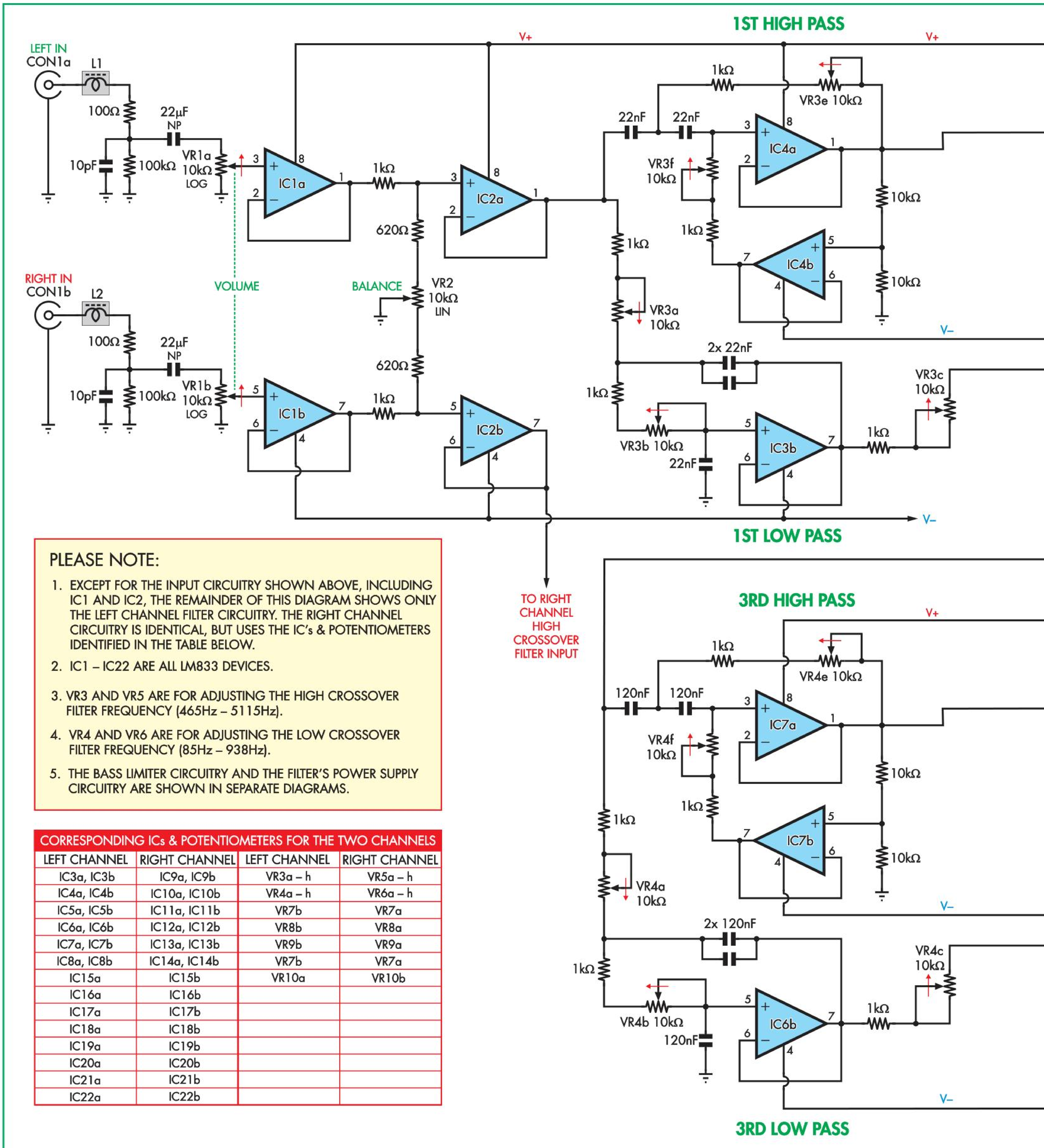
The attenuator comprises a 10kΩ resistor from the +15V supply, two 2.2kΩ resistors and another 10kΩ resistor to the –15V supply.

The centre point of the attenuator where the two 2.2kΩ resistors meet is connected to the ground (0V). A 5kΩ trimpot (VR11) connects across the two 2.2kΩ resistors and can be used to adjust the voltages at TP1 and TP2.

With VR11 set for 5kΩ, the voltage at TP1 and TP2 will be +1.57V and –1.57V respectively. This voltage can be reduced down to 0V, with VR11at the opposite extreme.

When the combined signal from IC23a and IC23b swings positive but less than the TP1 voltage, IC24b's output will be high; ie, above 0V. When the combined signal from IC23a and IC23b swings negative but less negative than TP2, IC24a's output will be low; less than 0V. In effect, IC24b and IC24a operate together as a window comparator.

The signal from IC24b is inverted by IC25b, changing any negative-going signal to positive-going. Then the positive going signals from IC25b


1ST HIGH PASS
LEFT IN
CON1a
L1
100Ω
22µF
NP
10pF
100kΩ
VR1a
10kΩ
LOG
IC1a
1kΩ
IC2a
620Ω
RIGHT IN
CON1b
L2
VOLUME
BALANCE
VR2
10kΩ
LIN
VR1b
10kΩ
LOG
IC1b
IC2b
V+
22nF
VR3e 10kΩ
VR3f
10kΩ
IC4a
IC4b
10kΩ
VR3a
10kΩ
2x 22nF
VR3c
10kΩ
VR3b 10kΩ
IC3b
V–
1ST LOW PASS
TO RIGHT CHANNEL HIGH CROSSOVER FILTER INPUT
3RD HIGH PASS
120nF
VR4e 10kΩ
VR4f
10kΩ
IC7a
IC7b
VR4a
10kΩ
2x 120nF
VR4c
10kΩ
VR4b 10kΩ
IC6b
3RD LOW PASS

PLEASE NOTE:

1. EXCEPT FOR THE INPUT CIRCUITRY SHOWN ABOVE, INCLUDING IC1 AND IC2, THE REMAINDER OF THIS DIAGRAM SHOWS ONLY THE LEFT CHANNEL FILTER CIRCUITRY. THE RIGHT CHANNEL CIRCUITRY IS IDENTICAL, BUT USES THE IC's & POTENTIOMETERS IDENTIFIED IN THE TABLE BELOW.
2. IC1 – IC22 ARE ALL LM833 DEVICES.
3. VR3 AND VR5 ARE FOR ADJUSTING THE HIGH CROSSOVER FILTER FREQUENCY (465Hz – 5115Hz).
4. VR4 AND VR6 ARE FOR ADJUSTING THE LOW CROSSOVER FILTER FREQUENCY (85Hz – 938Hz).
5. THE BASS LIMITER CIRCUITRY AND THE FILTER'S POWER SUPPLY CIRCUITRY ARE SHOWN IN SEPARATE DIAGRAMS.

CORRESPONDING ICs & POTENTIOMETERS FOR THE TWO CHANNELS

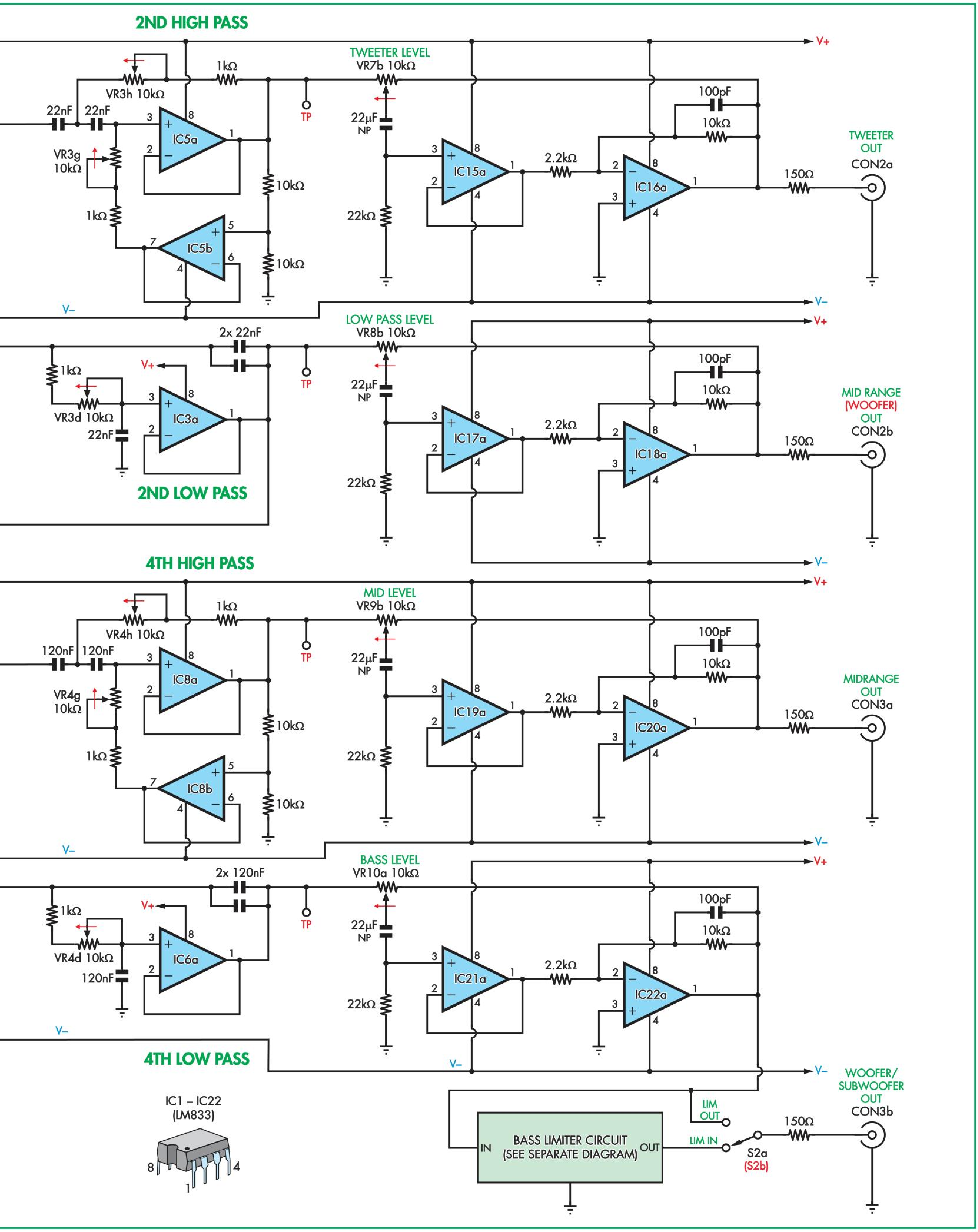
LEFT CHANNEL	RIGHT CHANNEL	LEFT CHANNEL	RIGHT CHANNEL
IC3a, IC3b	IC9a, IC9b	VR3a – h	VR5a – h
IC4a, IC4b	IC10a, IC10b	VR4a – h	VR6a – h
IC5a, IC5b	IC11a, IC11b	VR7b	VR7a
IC6a, IC6b	IC12a, IC12b	VR8b	VR8a
IC7a, IC7b	IC13a, IC13b	VR9b	VR9a
IC8a, IC8b	IC14a, IC14b	VR7b	VR7a
IC15a	IC15b	VR10a	VR10b
IC16a	IC16b		
IC17a	IC17b		
IC18a	IC18b		
IC19a	IC19b		
IC20a	IC20b		
IC21a	IC21b		
IC22a	IC22b		

3-WAY ADJUSTABLE ACTIVE CROSSOVER MAIN CIRCUIT (LEFT CHANNEL FILTERS ONLY)

Fig.5: the main portion of the *Active Crossover* circuit, built around 22 LM833 dual low-noise/low-distortion op amps. The layout is similar to that of block diagram Fig.2, so you should be able to identify the corresponding sections. VR3-VR6 are four eight-ganged 10kΩ linear potentiometers, which allow the corner frequency of each set of four active filters which makes up a crossover network to track. So only two adjustments need to be made to change the crossover point for either bass/midrange or midrange/tweeter. The bass limiter and power supply sections of the circuit are shown separately.

and IC24a are fed to diodes D1 and D2, respectively. So any positive-going signal from IC25b or IC24a will cause D1 or D2 to conduct and charge the 100µF capacitor via the 1kΩ resistor.

IC25a monitors the signal across the 100µF capacitor and drives LED1 and LED2 (in series) and these LEDs control the resistance of LDR1 and LDR2 to limit the bass signals when they exceed the thresholds set by TP1 and TP2.


2ND HIGH PASS
V+
TWEETER LEVEL
VR7b 10kΩ
1kΩ
VR3h 10kΩ
22nF
22nF
IC5a
VR3g 10kΩ
1kΩ
IC5b
10kΩ
10kΩ
TP
22µF NP
22kΩ
IC15a
2.2kΩ
IC16a
100pF
10kΩ
150Ω
TWEETER OUT
CON2a
V–
LOW PASS LEVEL
VR8b 10kΩ
2x 22nF
1kΩ
VR3d 10kΩ
22nF
IC3a
2ND LOW PASS
IC17a
IC18a
MID RANGE
(WOOFER)
OUT
CON2b
4TH HIGH PASS
MID LEVEL
VR9b 10kΩ
VR4h 10kΩ
120nF
120nF
IC8a
VR4g 10kΩ
IC8b
IC19a
IC20a
MIDRANGE OUT
CON3a
BASS LEVEL
VR10a 10kΩ
2x 120nF
VR4d 10kΩ
120nF
IC6a
IC21a
IC22a
4TH LOW PASS
WOOFER/ SUBWOOFER OUT
CON3b
IC1 – IC22 (LM833)
8
1
4
LIM OUT
LIM IN
BASS LIMITER CIRCUIT (SEE SEPARATE DIAGRAM)
IN
OUT
S2a
(S2b)

The time constant for the 100µF capacitor to discharge via the 100kΩ resistor is ten seconds. This time-constant prevents the audio signal from being modulated by the limiter circuit.

The associated 1kΩ resistor sets the attack time-constant to 100ms, so that limiting does not instantly occur with brief transients.

Note that the maximum 1.57V threshold at TP1 and –1.57V threshold

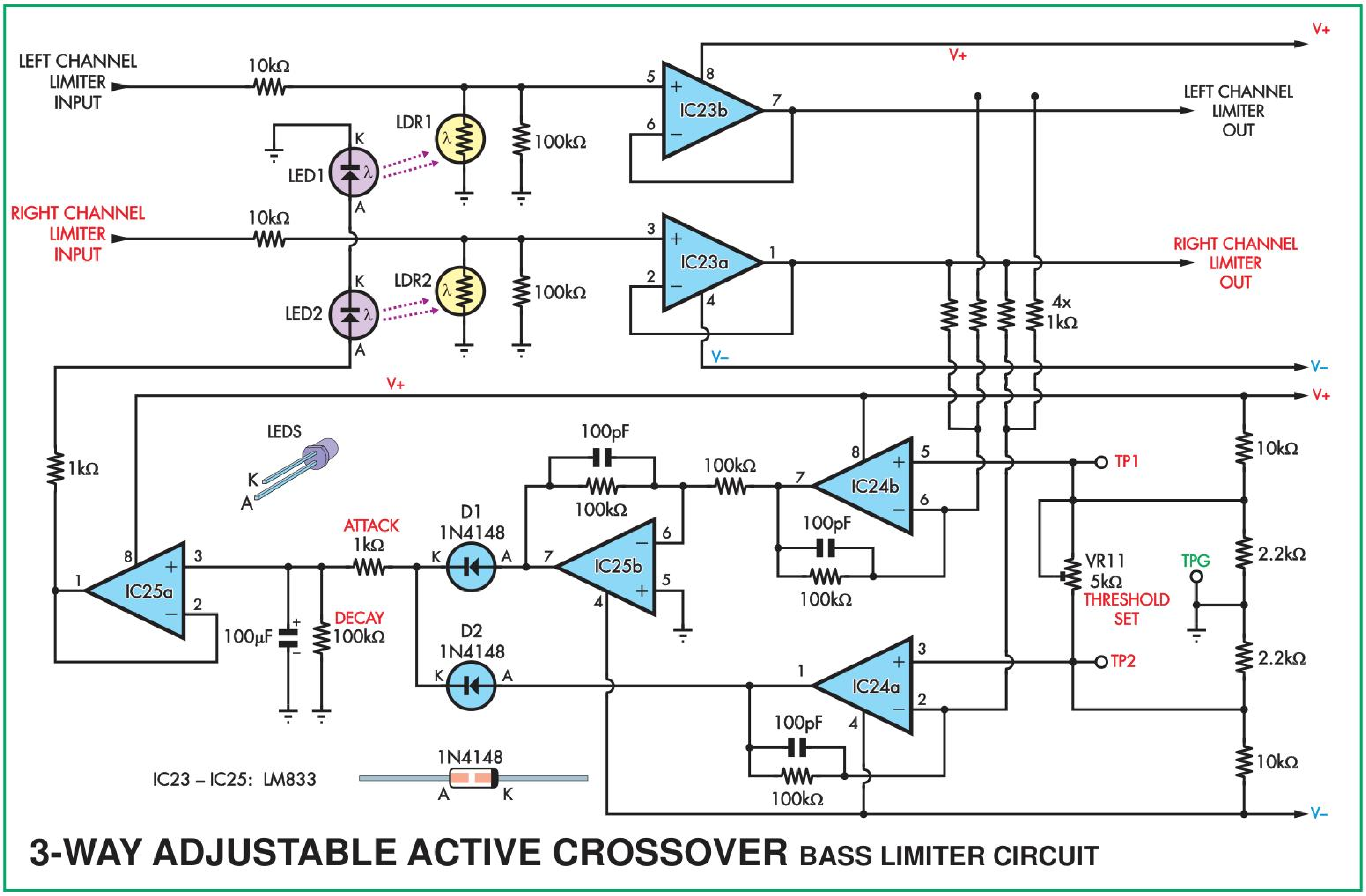

LEFT CHANNEL LIMITER INPUT
10kΩ
LDR1
100kΩ
LED1
K
A
IC23b
LEFT CHANNEL LIMITER OUT
V+
RIGHT CHANNEL LIMITER INPUT
10kΩ
LDR2
100kΩ
LED2
IC23a
RIGHT CHANNEL LIMITER OUT
4x 1kΩ
V–
V+
LEDS
1kΩ
IC25a
ATTACK 1kΩ
D1 1N4148
100pF
100kΩ
IC25b
100kΩ
IC24b
TP1
10kΩ
100pF
100kΩ
VR11 5kΩ THRESHOLD SET
TPG
2.2kΩ
100μF
DECAY 100kΩ
D2 1N4148
IC24a
TP2
2.2kΩ
100pF
100kΩ
10kΩ
IC23 – IC25: LM833
1N4148
3-WAY ADJUSTABLE ACTIVE CROSSOVER BASS LIMITER CIRCUIT

Fig.6: the bass-limiter circuitry, which prevents bass drivers that are driven with significant levels of gain from being overloaded. It uses pairs of LEDs and LDRs to form a variable-gain amplifier for each channel, similar to a compressor, but with a much longer attack and decay times.

at TP2 will start signal limiting for a sinewave that's 1.57V peak or 3.14V peak to peak. That is about 1.1V RMS.

Power supply

Fig.7 shows the power supply circuit. It can be powered using a centre-tapped 30V transformer or a 16VAC plugpack – either transformer feeds the bridge rectifier via switch S1. However, the bridge rectifier works differently, depending on which transformer is used.

The 16VAC plugpack connects via CON4, with one side going to ground while the centre-tapped transformer connects to 3-pin CON5. The net result is only two diodes are involved when the power comes via CON4 and S1a and we have half-wave rectification for the positive and negative rails fed to the 3-terminal 15V regulators.

When the power comes via CON5, the full-bridge rectifier is involved. Either way, the rectified DC is filtered using 470μF capacitors.

Next month

Hopefully, we have we whetted your appetite sufficiently with the description of the *Three-Way Active Crossover*.

Next month, we'll move on to the construction, setup and use of this project. So in the meantime, use the parts list to start gathering the bits you'll need (there are some that aren't normally available from your local lolly shop!) and get the PCB from the *EPE PCB Service*.

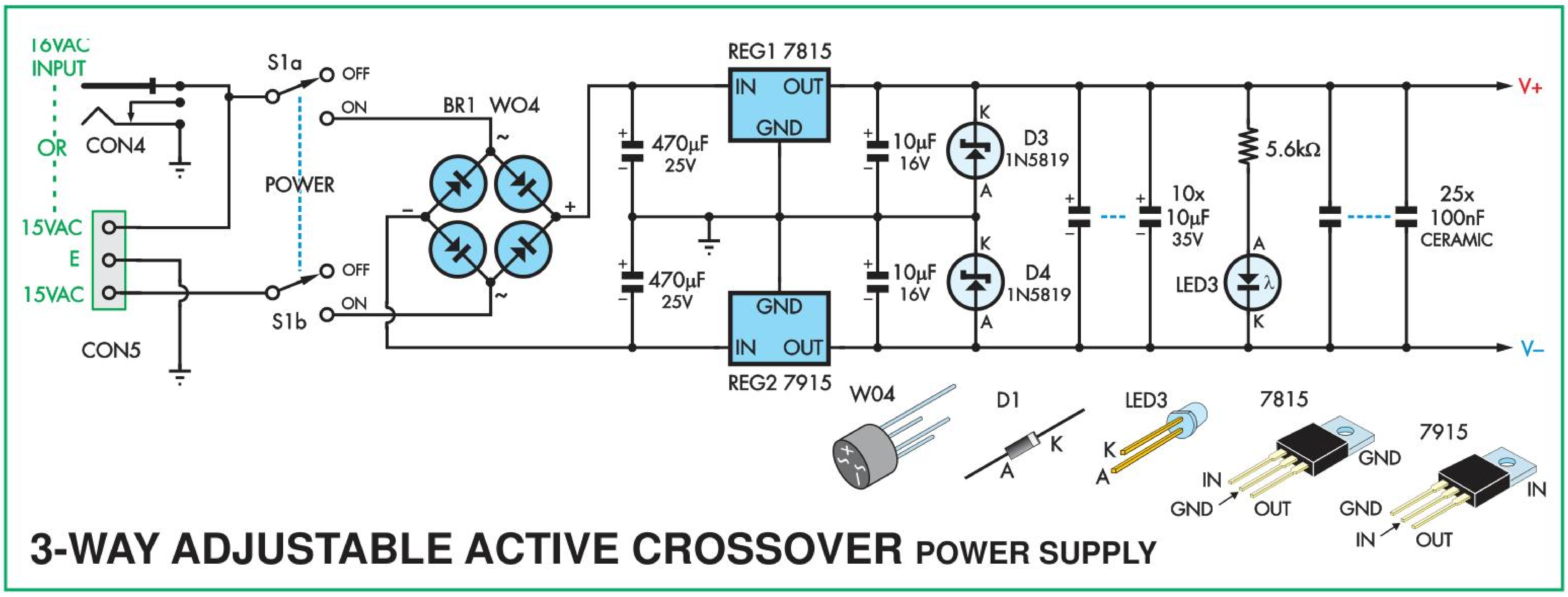

16VAC INPUT
CON4
OR
15VAC
E
15VAC
CON5
S1a
OFF
ON
POWER
S1b
OFF
ON
BR1 WO4
REG1 7815
IN OUT
GND
470μF 25V
470μF 25V
REG2 7915
10μF 16V
10μF 16V
D3 1N5819
D4 1N5819
10x 10μF 35V
5.6kΩ
LED3
25x 100nF CERAMIC
V+
V–
W04
D1
LED3
7815
7915
IN
GND
OUT
3-WAY ADJUSTABLE ACTIVE CROSSOVER POWER SUPPLY

Fig.7: the power supply section of the circuitry, which is on the same PCB as the rest. Power can come from either an AC plugpack or centre-tapped mains transformer. The transformer output is rectified, filtered and regulated to produce the ±15V supply rails for the op amps.

EXCLUSIVE OFFER

Win a Microchip SAMA5D27-SOM1-EK1 Development Board

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip SAMA5D27-SOM1-EK1 development board (ATSAMA5D27-SOM1-EK1).

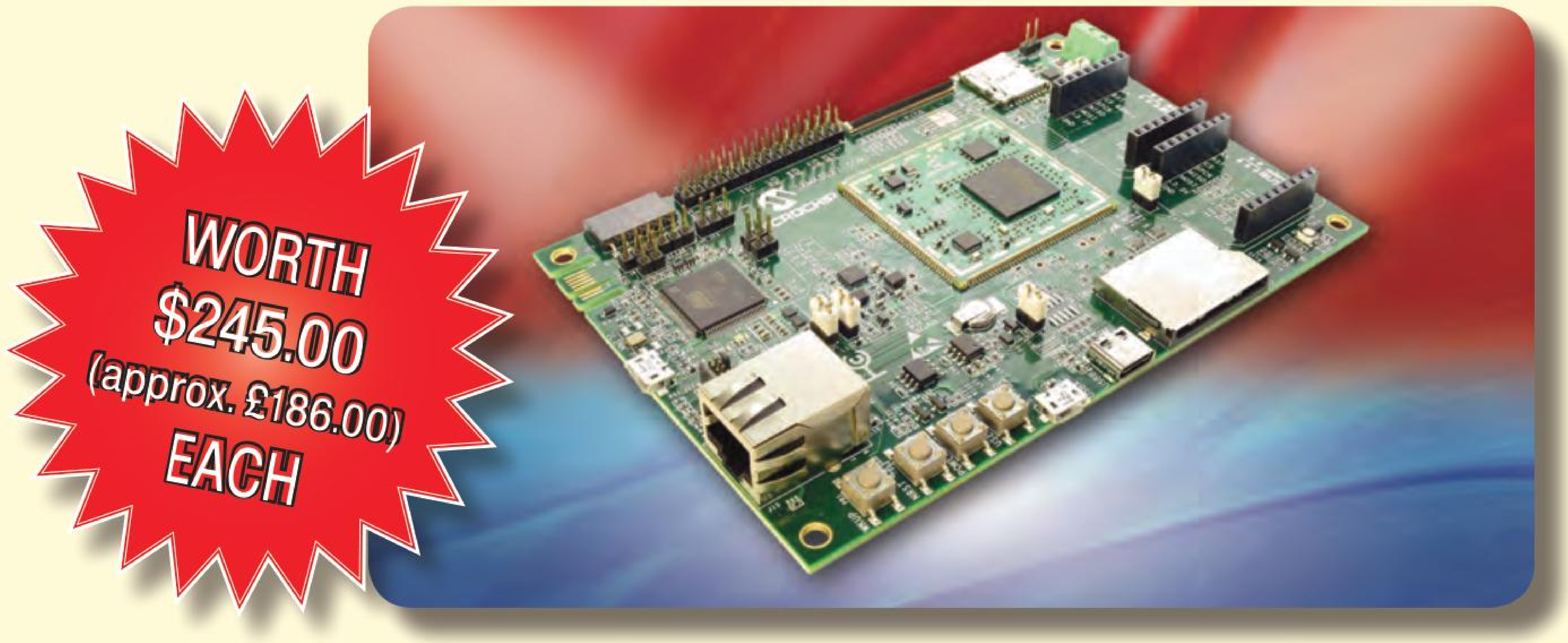
The SAMA5D27-SOM1-EK1 development board is a fast prototyping and evaluation platform for the SAMA5D27-SOM1, which helps ease development of industrial-grade microprocessor-based systems.

The ATSAMA5D27-SOM1, which contains the ARM Cortex-A5 ATSAMA5D27C-D1G-CU System in Package (SiP), greatly simplifies design by integrating the power management, non-volatile boot memory, Ethernet PHY and high-speed lower-power DDR2 memory onto a small, single-sided PCB. The SAMA5D27 SOM1 is built on a common set of proven Microchip components and limits the design rules of the main application board, reducing overall PCB complexity and cost.

Linux-based applications have access to Microchip's extensive set of device drivers, middleware and application layers for the embedded market at no charge. All of Microchip's Linux development code for the SiP and SOM are mainlined in the Linux communities.

The kit comprises a baseboard with a soldered ATSAMA5D27-SOM1 module, which features an ATSAMA5D27C-D1G-CU SiP embedding a one-gigabit (128MB) DDR2 DRAM.

The board features a wide range of peripherals, as well as a user interface and expansion options, including two mikroBUS click interface headers to support MikroElektronika click boards and one PMOD interface.



HOW TO ENTER

For your chance to win a Microchip SAMA5D27-SOM1-EK1 development board, visit: **http://page.microchip.com/epe-atsam.html** and enter your details in the online entry form.

CLOSING DATE

The closing date for this offer is 30 September 2018.

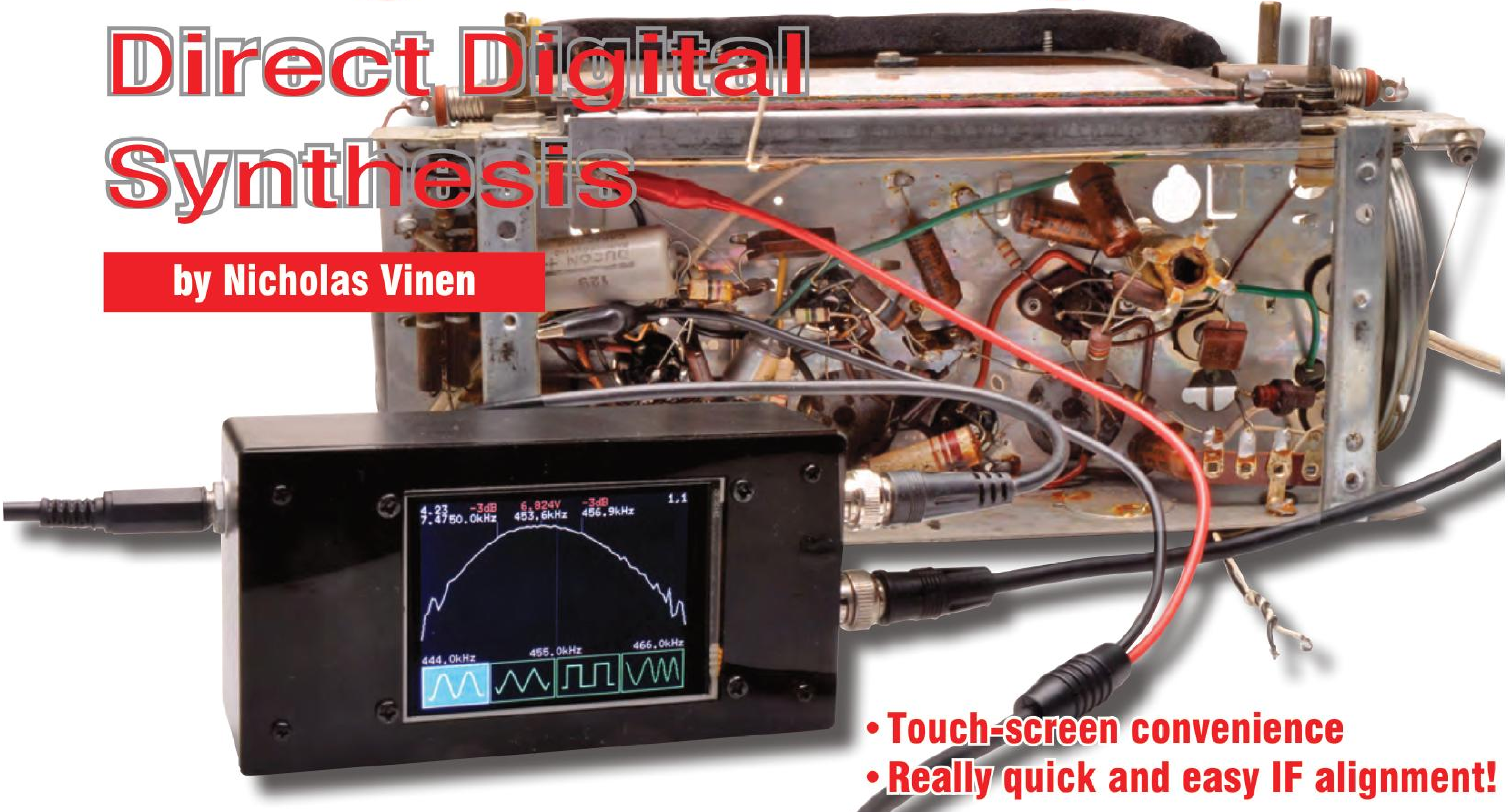
May 2018 ISSUE WINNER

Mr Richard Pontey from Pontefract, West Yorkshire

He won a Microchip Curiosity HPC Development Board, valued at £28.50

Dead-easy Superhet IF Alignment using Direct Digital Synthesis

by Nicholas Vinen



- Touch-screen convenience
- Really quick and easy IF alignment!

This project is based on the touch-screen *Micromite DDS Signal Generator* project and makes aligning the IF stage of superhet sets a snap, whether they are valve or transistor-based. It also lets you examine the IF stage bandwidth, which gives a good indication of the set's selectivity, as well as the shape of the IF curve.

In **the simplest terms,** a superheterodyne AM radio works by mixing (ie, 'heterodyning') the radio station signal with a tracking oscillator signal that has a fixed frequency offset above (ie, 'super') that of the tuned station.

The output of the mixer includes components at the sum and difference frequencies of the two input signals. The following stages reject all but the difference frequency and this carries the same audio (amplitude) modulation as the incoming signal from the radio station.

The difference frequency is known as the 'intermediate frequency' (IF). IF circuitry normally comprises two stages with tuned resonant circuits, each involving a transformer with adjustable cores (slugs). In more detail, the primary and secondary windings of each transformer have parallel capacitors and their cores need to be adjusted so that their resonant frequency matches the IF, eg, 455kHz or 450kHz.

Adjusting the transformers in this way maximises the gain of the radio and the whole process is referred to as IF alignment. IF alignment also optimises the Q of each stage and this increases the rejection of unwanted signals (outside the tuned circuit's resonant range).

This has the effect of increasing the selectivity of the radio, which means that it is easier to tune when stations are crowded together on the dial.

Normal alignment also involves adjusting the antenna input circuits so that stations at the top and bottom of the dial (ie, the full timing range) are actually received at the marked points (ie, the station call sign or the transmitter frequency on the dial).

Note that some sets with a wide audio bandwidth (say 10kHz or more) may have the IF transformer cores adjusted to slightly different frequencies, say 447kHz and 463kHz, in the case of a 455kHz IF. This 'staggered tuning' gives a wider audio bandwidth but slightly lower gain.

For readers who are new to AM radio – probably our younger subscribers! – and who wish to know more, we will be running a great two-part AM radio project in the November and December 2018 issue of *EPE*. This will include a good explanation of the principles of superhet operation.

Aligning the IF stages

There are a number of methods by which you can do alignment on an AM radio, but the simplest approach involves injecting a signal into the set which can be set to the intermediate frequency.

If this signal is modulated (typically at 400Hz), you can easily judge the effect of your adjustments by the loudness of the tone in the radio's loudspeaker. That means you need a modulated RF oscillator which can be set to precisely 450 or 455kHz.

It is also desirable that its output is a clean sinewave, ie, with few harmonics to cause problems in the alignment results.

Frequency (Hz)
0 455 000
IF Align
Level
☐ AM
(1 kHz)
100

It's all housed in a small jiffy box... and if you're into restoring vintage radios, for example, you'll find this the best thing you've ever seen since sliced bread!

Unfortunately, the output waveform of most old valve and transistor RF oscillators is surprisingly distorted and their output amplitude can also vary significantly as the frequency is changed.

However, there is a much easier and more elegant way and here is where modern technology comes to the rescue.

Sweep oscillator

What we would really like is to plot the set's detector output against the injected frequency so that we can actually see what the IF stage frequency response looks like.

That's just what this project does. It produces a signal which is swept over a range of frequencies around the nominal IF and it measures the output of the voltage detector (usually a diode just preceding the volume control).

The varying DC output can then be plotted on an LCD screen.

You can set the centre frequency and span, and it automatically scales the vertical axis and adds cursors showing the peak frequency and (if visible) –3dB points. That makes doing the IF alignment, and even setting the IF bandwidth, easy!

But we are getting ahead of ourselves. Fig.1 shows the concept. The sweep oscillator can be thought of as an oscillator which can be set to vary in a linear fashion from say, 440kHz to 470kHz, repeatedly.

This signal is connected to the input of the IF stages and the output of the detector is connected to an oscilloscope. But, we have combined the sweep oscillator and the oscilloscope screen into the one unit.

For the sweep oscillator, we're using a direct digital synthesis (DDS) module based on the Analog Devices AD9833 IC.

Then we're using the *Micromite LCD BackPack* to provide the oscilloscope function, to display the result.

Because the Micromite is controlling the DDS, it can synchronise the plotted result on the screen with the frequency of the sweep oscillator.

The hardware used in this project is pretty much the same as that in the *Micromite BackPack Touchscreen DDS Signal Generator* that was published in the April 2018 issue.

The main changes are to the software, to provide the sweep and plotting function. There's just a slight hardware change, to provide the required analogue voltage measurements.

Circuit operation

The circuit diagram for the *DDS IF Alignment* unit is shown in Fig.2. Most of the work is done by the Micromite software running on the *BackPack* and the arbitrary waveform generator module which contains the AD9833 IC.

If you compare this diagram to the one from the Touchscreen *DDS Function Generator* in the April 2018 issue (on page 26), you will see a few minor changes.

First, we have changed the coupling capacitors from the PGA (programmable gain amplifier) output of the DDS module to the output connectors to a single 10nF 630V type, primarily to provide protection for the DDS module from accidental connections to HT voltages in valve radios.

We have also added a 10kΩ resistor in series, to limit inrush current in the case of a short circuit.

This offers the possibility of injecting the signal into HT-biased parts of the circuit, but as we will see later, that is generally not necessary.

We've omitted the attenuated output terminal since you can adjust the sinewave amplitude output of the DDS via the touchscreen and you can also control the amount of signal coupling into the radio antenna by how closely you place the leads (more on that later).

We haven't bothered with any DC biasing of the output since that will generally be accomplished in the set if you are using direct signal injection.

In place of the trigger output used in the original *DDS Generator* project, we have an analogue input that's intended to monitor the DC output of the detector or AGC (automatic gain control) signal.

This gives the unit direct feedback on the amount of signal passing through the IF stage. This goes back to pin 24 on the *BackPack* since this is an analogue input.

It's protected from accidental high-voltage application via a 4.7MΩ series resistor and this also forms a divider with the 1MΩ resistor to pin 22, if pin 22 is actively driven.

If pin 22 is left floating by the software, it has little effect on the voltage at pin 24.

For radios which have a negative AGC/detector output (the majority), pin 22 is driven high, to +3.3V. This allows pin 24 to measure voltages down to –15.5V (3.3V × (–1) × [4.7MΩ ÷ 1MΩ]).

To measure positive voltages, pin 22 can be left floating for high sensitivity (0V to 3.3V) or driven low for low-sensitivity (0V to 18.8V) measurements. This is all under the control of the software.

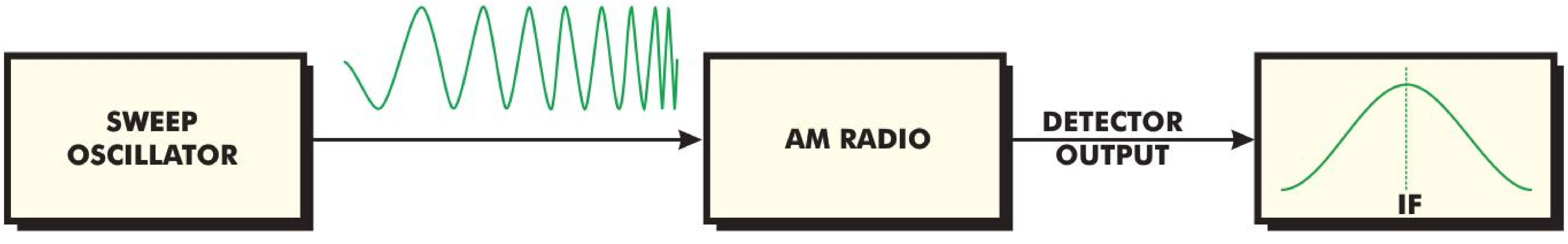


Fig.1: an overview of how this unit can be used to plot the frequency response of the IF stage in a radio. A sinewave signal is produced which sweeps from just below the intermediate frequency to just above. This is injected into the set via its antenna. The detector voltage is then plotted against the sweep frequency on an LCD screen to produce a frequency response plot. Note that the sweep oscillator's output is not amplitude modulated.

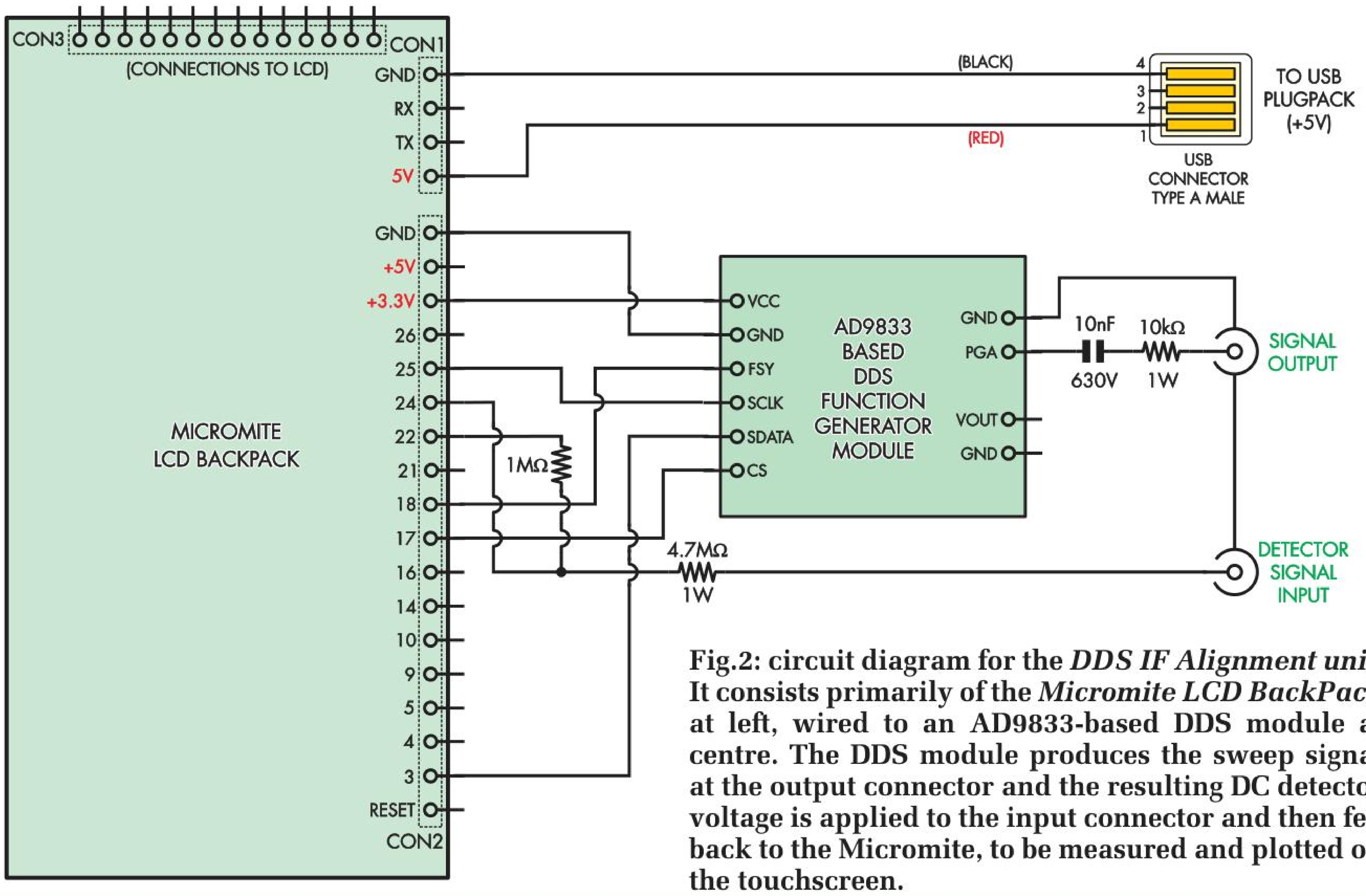

CON3
(CONNECTIONS TO LCD)
CON1
GND
RX
TX
5V
GND
+5V
+3.3V
26
25
24
22
21
18
17
16
14
10
9
5
4
3
RESET
CON2
MICROMITE
LCD BACKPACK
1MΩ
(BLACK)
(RED)
4
3
2
1
TO USB
PLUGPACK
(+5V)
USB
CONNECTOR
TYPE A MALE
VCC
GND
FSY
SCLK
SDATA
CS
AD9833
BASED
DDS
FUNCTION
GENERATOR
MODULE
GND
PGA
VOUT
GND
10nF
630V
10kΩ
1W
SIGNAL
OUTPUT
4.7MΩ
1W
DETECTOR
SIGNAL
INPUT

Fig.2: circuit diagram for the *DDS IF Alignment unit*. It consists primarily of the *Micromite LCD BackPack* at left, wired to an AD9833-based DDS module at centre. The DDS module produces the sweep signal at the output connector and the resulting DC detector voltage is applied to the input connector and then fed back to the Micromite, to be measured and plotted on the touchscreen.

We won't go into a great deal of detail on the operation of the AD9833 DDS module.

This was covered in a dedicated article in the June 2018 issue of *EPE*. (It was also explained in the article on the *DDS Signal Generator* in the April 2018 issue.)

In brief, software running on the *LCD BackPack* sends commands to the DDS module over a three-wire SPI (serial peripheral interface) bus comprising pins SCLK (clock), SDATA (data) and FSY (module select).

The same SPI bus is used to communicate with a digital attenuator in the same module, except that the CS (chip select) line is pulled low when communicating with it, rather than FSY.

By sending serial commands to the AD9833, the PIC32 in the *BackPack* can set the output waveform type (sine, triangle, square), the frequency (from 0.1Hz to 12.5MHz), the phase and it can also put the AD9833 IC into low-power sleep mode, or wake it up.

By sending commands to the digital attenuator, the output level can be changed in 255 steps, over a range of about 4mV to 1V RMS.

Software operation

The software for this project is based directly on the software for the *DDS Signal Generator* (*EPE*, April 2018) and retains all of its original features.

We've simply added an 'IF Align' button to the main screen (see Fig.3).

Once you've set up the generator to produce a sinewave at the expected intermediate frequency, press this button and the unit will go into sweep mode.

By default, it will sweep from 10kHz below the current centre frequency to 10kHz above (ie, a span of 20kHz). Each sweep takes a couple of seconds.

To do a sweep, the unit first sets the DDS output frequency to the lower end of the sweep range, then after a

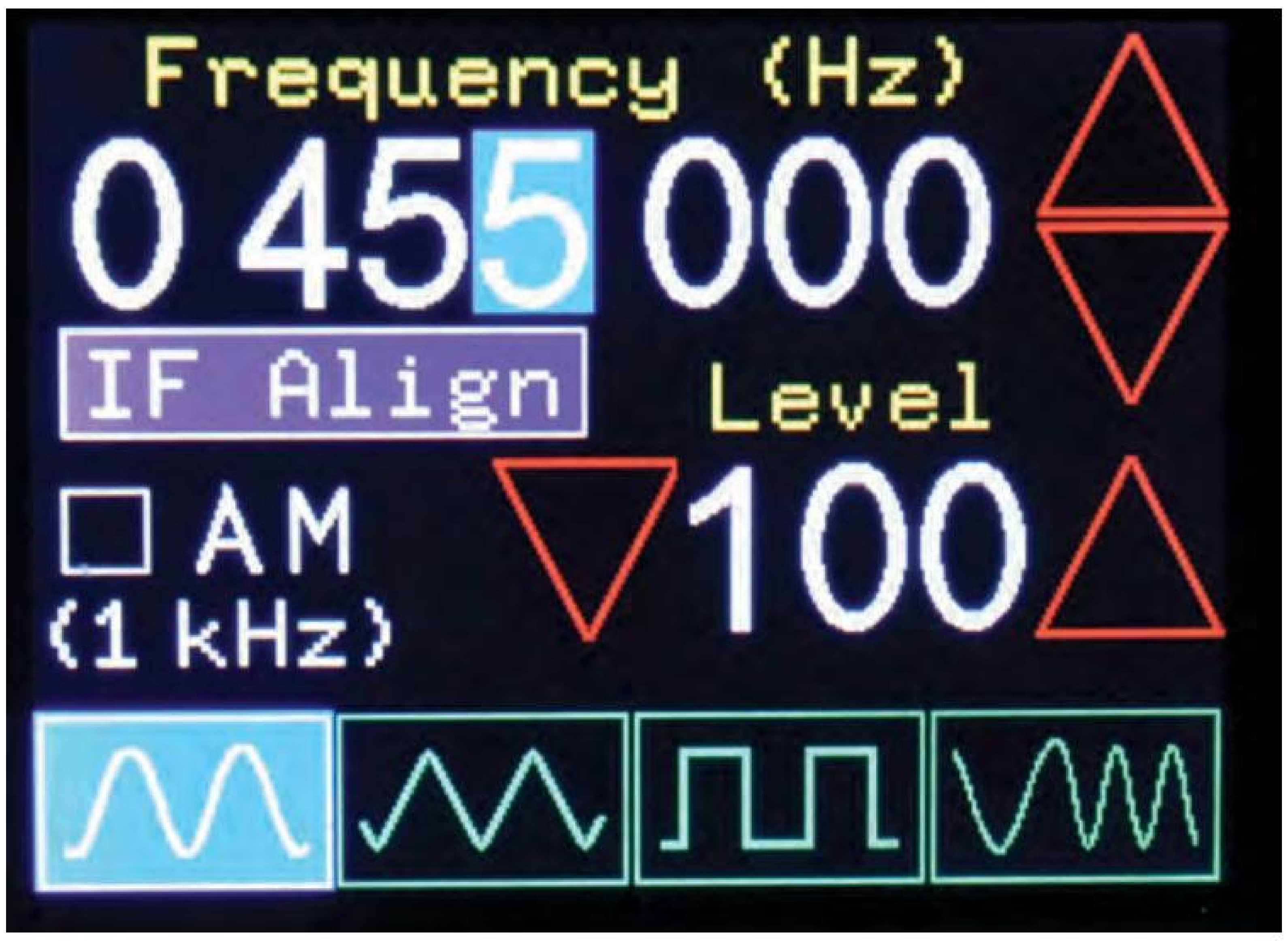

Frequency (Hz)
0 455 000
IF Align
Level
☐ AM
(1 kHz)
100

Fig.3: the modified main screen from Geoff Graham's *DDS Signal Generator*. Note the new 'IF Align' button at centre left. You can still use the unit as a signal generator, with all the same functions of the original unit. We simply added the extra functions required for IF alignment, accessed via this new button.

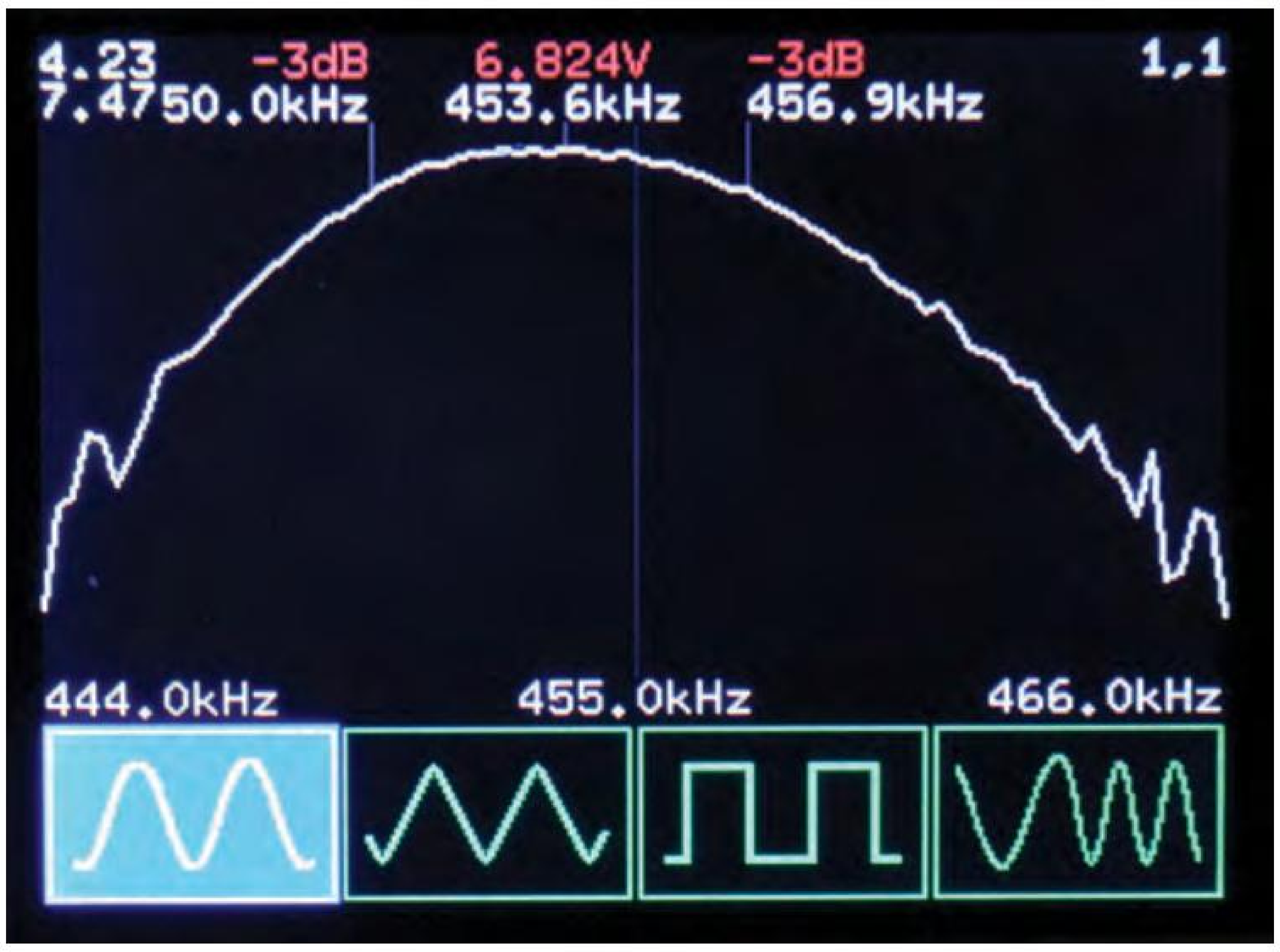

4.23
7.4750.0kHz
-3dB
6.824V
453.6kHz
-3dB
456.9kHz
1,1
444.0kHz
455.0kHz
466.0kHz

Fig.4: we hooked our test unit up to an HMV 64-52 'Little Nipper' valve superhet and this is the result. The plot shows that the IF stage needs some re-alignment as its peak response is not at 455kHz. Note the cursors indicating the peak and (approximate) –3dB points. The output lead was simply placed near the ferrite rod antenna while the output of the detector was taken from the top of volume control pot VR1 (which doubles as the AGC signal, fed to R4).

short delay, measures the voltage at the detector input. It then increases the output frequency by 1/80th of the span and measures the detector input voltage again.

Once it has at least two measurements, it updates the display with a short line segment, forming that portion of the IF curve plot.

This process is repeated until the frequency is at the top of the span (ie, after 80 steps) and the curve plot is complete.

The unit then repeats this process forever, so that the plot is constantly being updated.

Each time a sweep is completed, it analyses the data and finds the maximum value, then draws a cursor, which includes text that shows the peak frequency and voltage reading, plus a vertical line down to that part of the curve.

It then looks for the –3dB points on either side of this peak and if found, draws cursors for them too, including the frequency readings.

The mode buttons that are normally at the bottom of the screen in the *DDS Signal Generator* are still present in sweep mode, so pressing any of these will take you out of sweep mode and back into one of the normal signal generator modes. (Note that other areas of the screen can be touched to change the sweep parameters.)

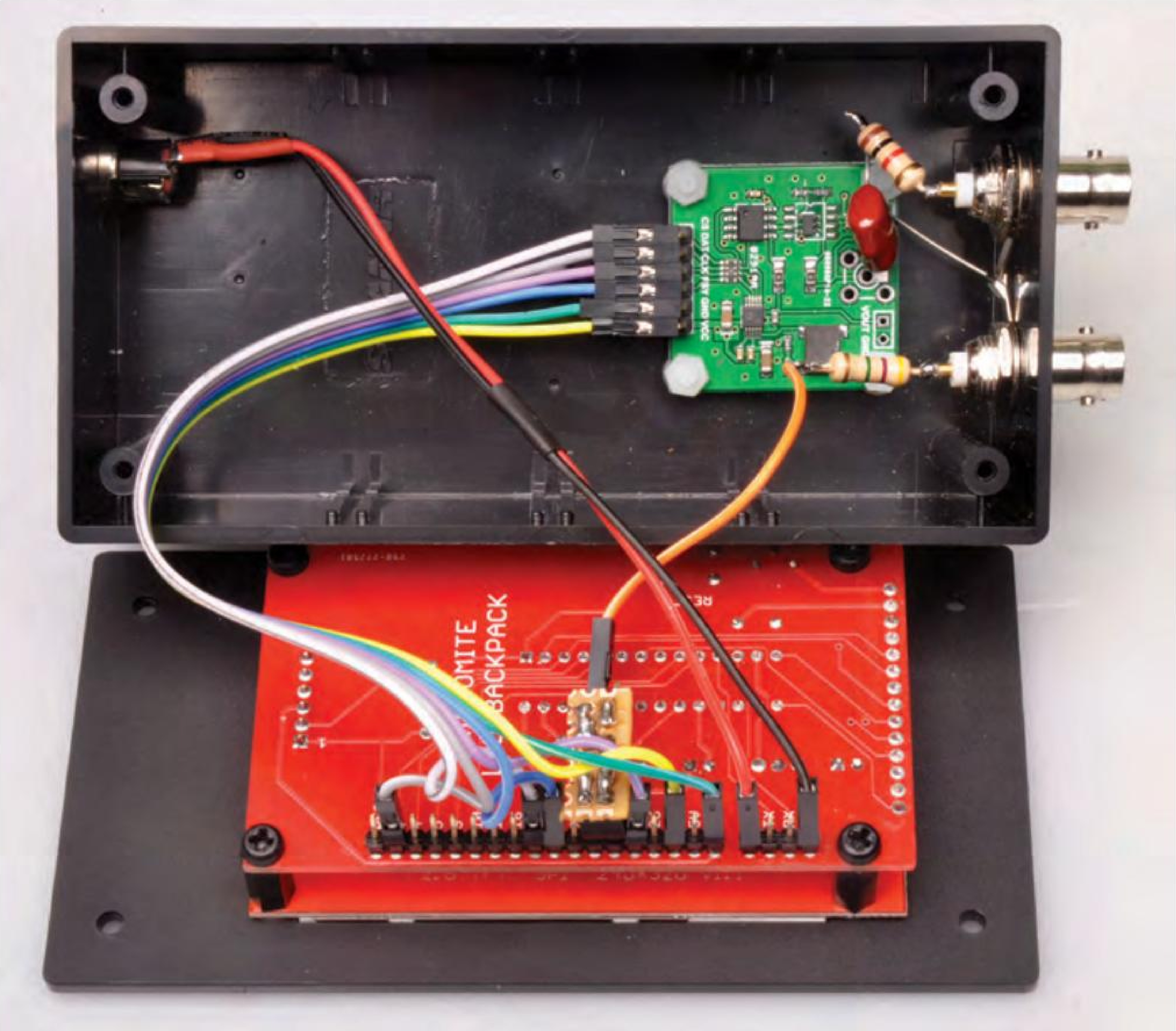
Parts list – DDS IF Alignment

1 2.8-inch Micromite LCD BackPack kit (available from **micromite.org**) with microcontroller programmed for DDS IF Alignment (DDSIFAlign.HEX – specify if you need this software included in your BackPack order from micromite.org)
1 DDS Function Generator module with AD9833, AD8051 and MCP41010 ICs (SILICON CHIP online shop Cat SC4205)
1 UB3 plastic 'jiffy' box
4 M3 × 10mm nylon machine screws
12 M3 nylon hex nuts
11 short single-pin female-female DuPoint jumper leads
1 USB charger with USB-to-DC-plug cable (see Fig.7)
1 chassis-mount DC barrel socket, to suit cable
2 chassis-mount BNC sockets
1 10nF 630V polyester capacitor
1 4.7MΩ 1W resistor
1 1MΩ 0.25W resistor
1 10kΩ 1W resistor

Micromite parts

We strongly recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil Boyce, who runs micromite.org, can supply kits, programmed ICs, PCBs and many of the sensors and other devices mentioned in recent articles – in fact, just about anything you could want for your Micromite endeavours. Phil works closely with Geoff Graham and is knowledgeable about the whole series of Micromite microcontrollers.

You can press on the centre frequency, at the bottom of the plot, to change it (a keyboard will appear). Similarly, touching either the lowest or highest sweep frequency in the bottom corners will let you set the frequency span.



Here's how it all fits inside a UB3 Jiffy Box, albeit with a new laser-cut acrylic front panel. The 10kΩ 1W resistor attached to the upper BNC socket appears to go to nowhere in this photo; in fact it is soldered to the 10nF capacitor immediately below it. Similarly, the orange cable connecting to the *BackPack* solders direct to the end of the 4.7MΩ 1W resistor. Note also the small piece of strip board attached to the *MicroMite BackPack* PCB – we used this to more firmly anchor the 1MΩ 1W resistor which connects between pins 22 and 24 of the *BackPack*. Incidentally, 1W resistors were chosen not for their power dissipation but instead for their voltage ratings, assuming the DDS module will be used with the higher voltages of valve radios.

If you press on one of the cursors at the top of the screen, you will change the cursor update interval.

Normally, they are updated each time a sweep is completed, but you can set them to change on every second or fourth sweep, to give you more time to read them off, by pressing on the cursors.

The first number in the top-right-hand corner of the plot (before the comma) indicates the current cursor sweep update interval.

The second of these two numbers indicates the detector voltage input mode. The default mode is '1', which inverts the voltage measured and gives a maximum input reading of around –16V.

In this mode, the pin 22 output is driven high, in order to shift negative input voltages up into the range of 0-3.3V, so the micro can measure them.

Pressing on the middle of the screen will change this mode to '2', which sets the pin 22 output low.

Thus, the unit measures positive voltages, from 0V up to around +19V. Pressing again will change the mode to '0', which causes pin 22 to float and so the input voltage measurement range is 0V to 3.3V. Another press will take you back to mode 1.

The input impedance is around 5MΩ, regardless of mode.

Note that current does flow into pin 24 when making analogue measurements and the high source impedance

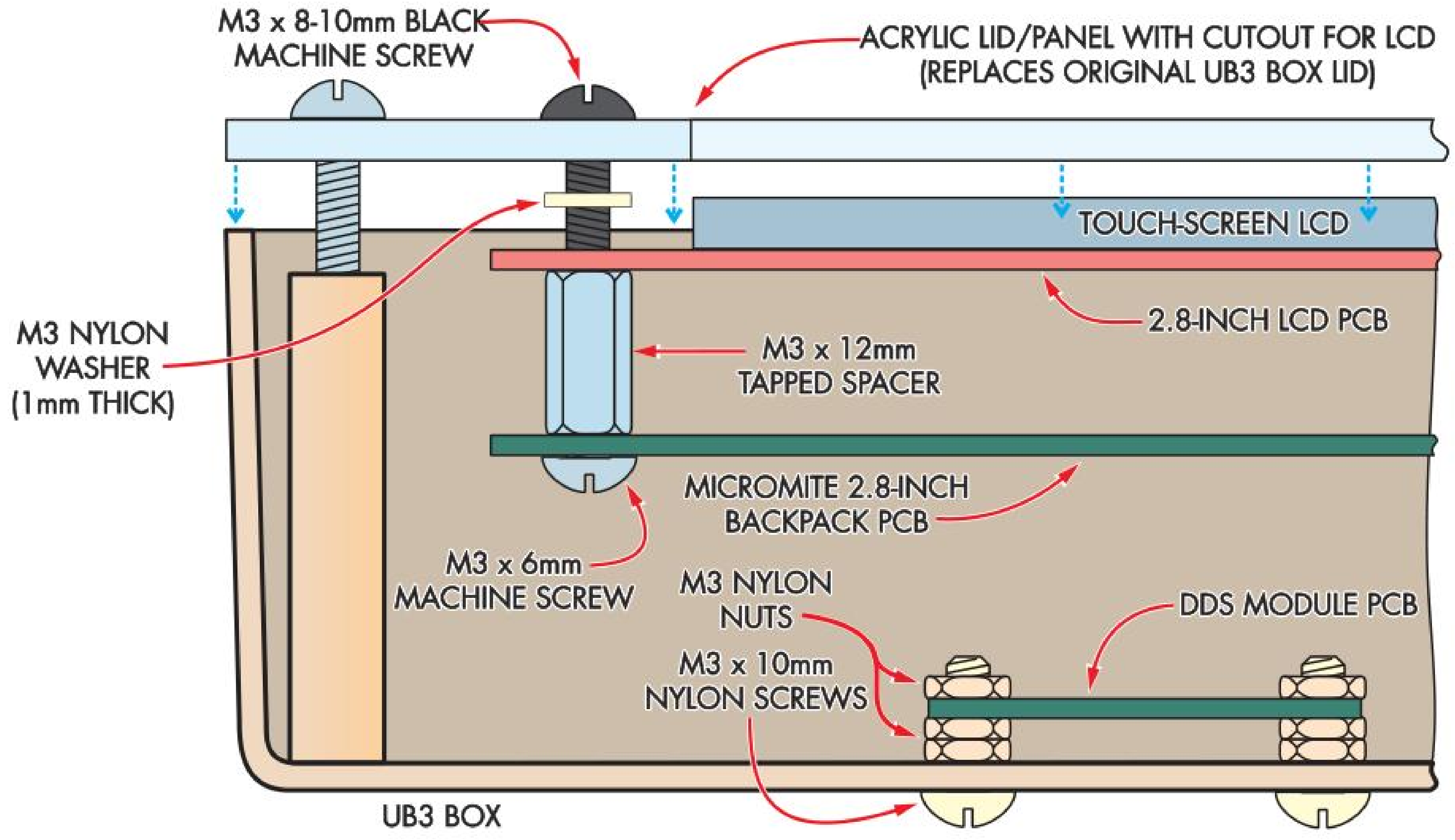

M3 x 8-10mm BLACK MACHINE SCREW
ACRYLIC LID/PANEL WITH CUTOUT FOR LCD (REPLACES ORIGINAL UB3 BOX LID)
TOUCH-SCREEN LCD
M3 NYLON WASHER (1mm THICK)
2.8-INCH LCD PCB
M3 x 12mm TAPPED SPACER
MICROMITE 2.8-INCH BACKPACK PCB
M3 x 6mm MACHINE SCREW
M3 NYLON NUTS
DDS MODULE PCB
M3 x 10mm NYLON SCREWS
UB3 BOX

Fig.5: this diagram shows how the *LCD BackPack* is attached to the underside of the 3mm laser-cut lid, while the DDS module is mounted in the bottom of the jiffy box.

of 4.7MΩ, due to the series resistor, will cause errors in the readings.

But the whole measurement process is quite approximate, due to various factors such as AGC operation, imperfect coupling of the test signal into the set, non-linearity in the detector and background noise being picked up by the set's antenna (unless it is disconnected).

In general, the measurements are close enough to get a pretty good plot of the IF stage's response and make any necessary adjustments.

Construction

The majority of the assembly required for this project is to build the *LCD BackPack module*, available from our recommended online Micromite vendor: **micromite.org**

You can use the plain *BackPack* kit and load the BASIC code for the DDS IF Alignment yourself, using a USB/serial adaptor and the free MMEdit software. Or for the same price, you can purchase a kit with the software pre-loaded on the microcontroller.

Also available is a laser-cut lid to replace the UB3 jiffy box lid, with the required cut-out and holes already drilled.

Assembly is quite straightforward, simply fit all the parts where indicated on the PCB silkscreen label. For full details, see the May 2017 article describing the *BackPack,* but most constructors won't have any trouble figuring it out.

Make sure the 28-pin socket goes in with its notch in the position shown, and when you plug the micro into its socket, its pin 1 dot needs to go near the notch.

The female header for the LCD and 6-pin right-angle in-circuit serial programming (ICSP) header both go on the same side as the micro and related components, while the two vertical male pin headers for the input/output connections are soldered on the back.

Once the module is complete, power it up to make sure it works and then attach it to the underside of the lid with 1mm-thick nylon washers as spacers.

The touchscreen is held onto the main board by screws that pass through the lid, these spacers, the LCD module and then into the spacers mounted on the main board. The overall arrangement is shown in Fig.5.

BackPack capacitors

A short point about the three 10µF/47µF capacitors; note that they were shown as through-hole tantalum types in the May 2017 article, and you can use these, but we prefer to use SMD ceramics as they are more reliable. The ceramic capacitors are not polarised and the PCB has pads to suit either type.

The kit is normally supplied with two SMD capacitors in one pack and one in another; the one by itself is the 47µF type. However, it doesn't actually matter where you solder them since we

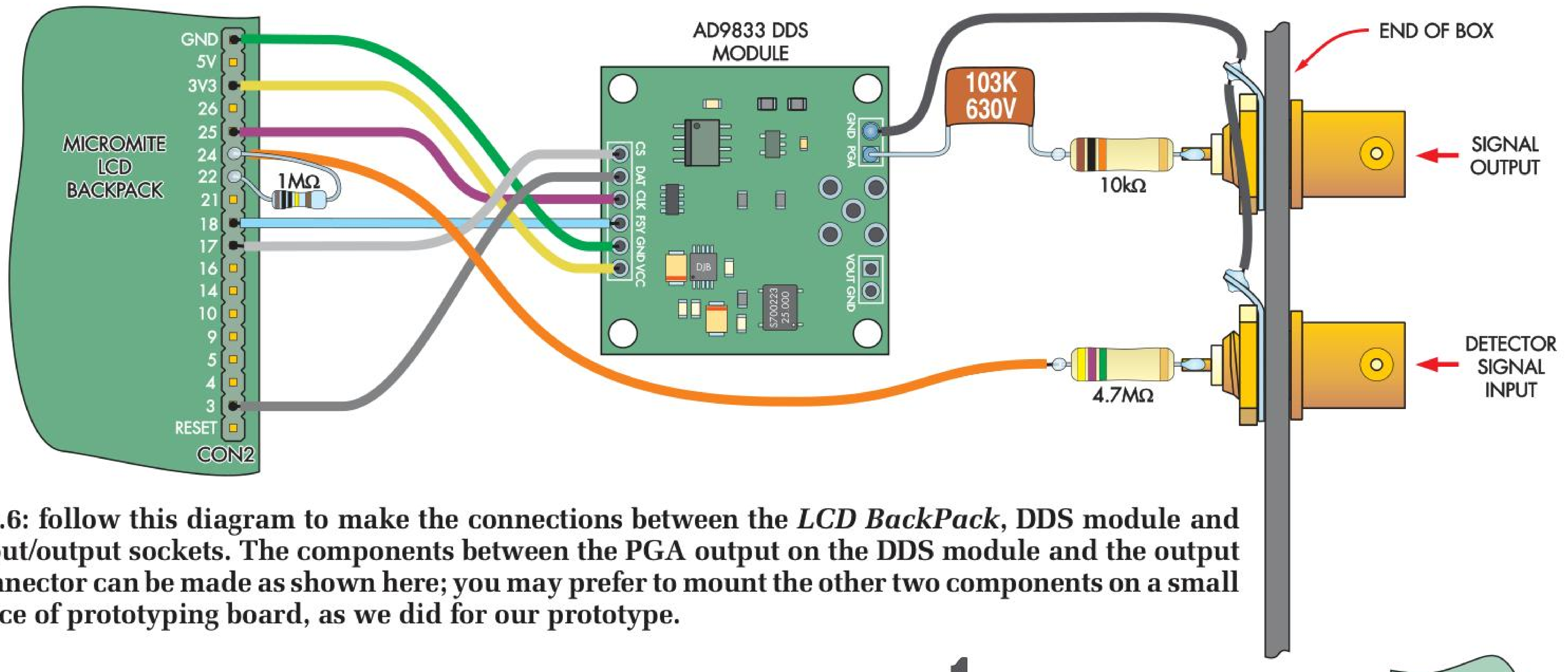

MICROMITE LCD BACKPACK
GND
5V
3V3
26
25
24
22
21
18
17
16
14
10
9
5
4
3
RESET
CON2
1MΩ
AD9833 DDS MODULE
CS
DAT
CLK
FSY
GND
VCC
GND
PGA
VOUT
GND
DJB
S700223
25.000
103K 630V
10kΩ
4.7MΩ
END OF BOX
SIGNAL OUTPUT
DETECTOR SIGNAL INPUT

Fig.6: follow this diagram to make the connections between the *LCD BackPack*, DDS module and input/output sockets. The components between the PGA output on the DDS module and the output connector can be made as shown here; you may prefer to mount the other two components on a small piece of prototyping board, as we did for our prototype.

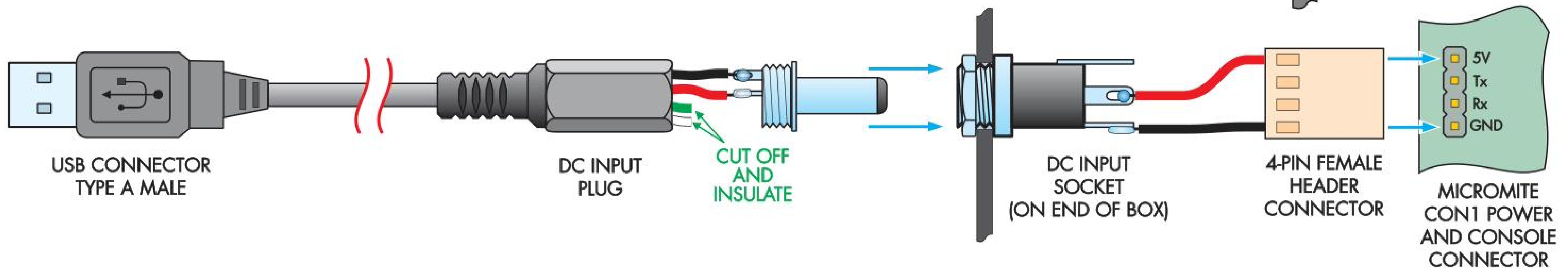
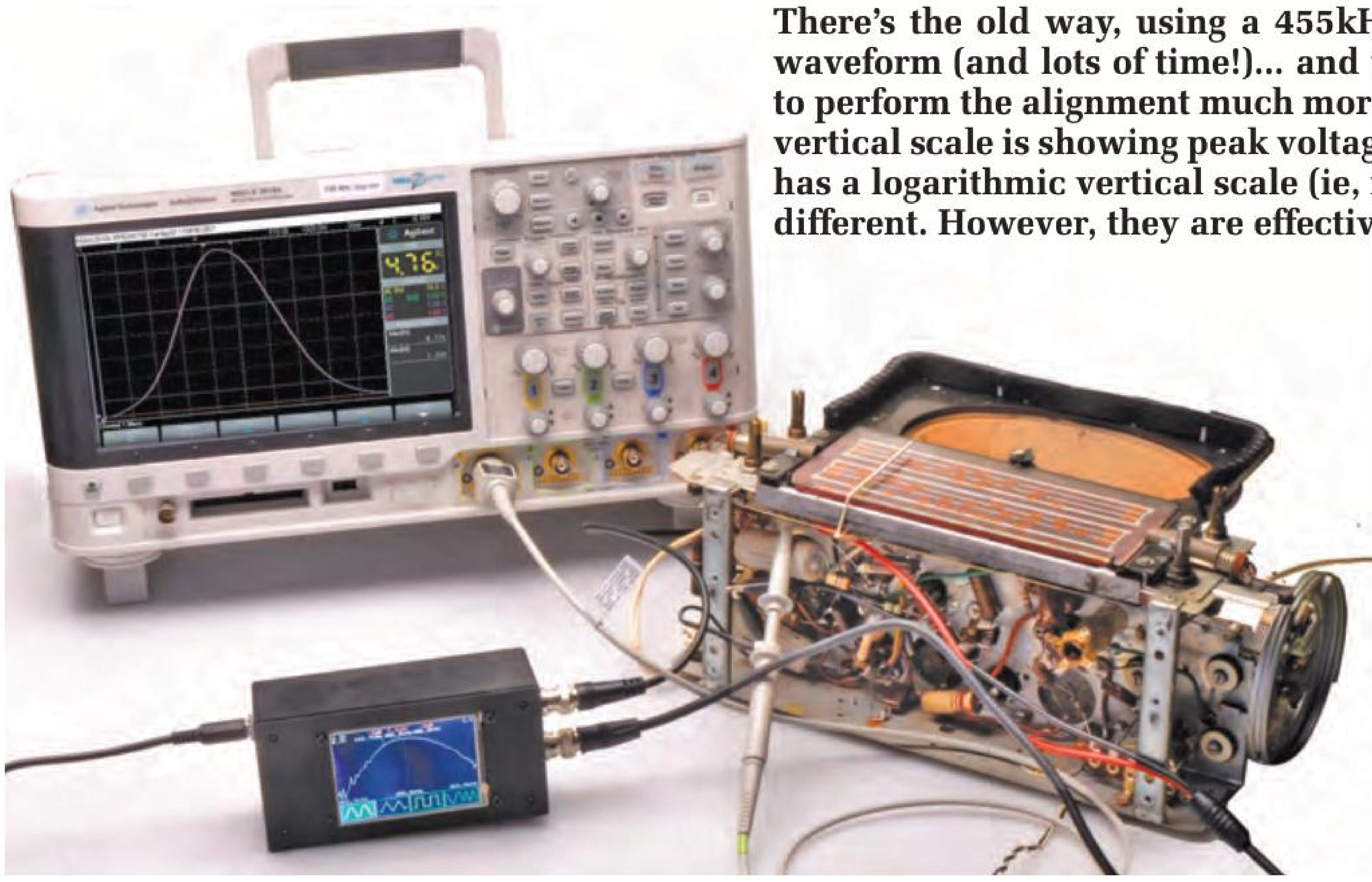

USB CONNECTOR TYPE A MALE
DC INPUT PLUG
CUT OFF AND INSULATE
DC INPUT SOCKET (ON END OF BOX)
4-PIN FEMALE HEADER CONNECTOR
5V
Tx
Rx
GND
MICROMITE CON1 POWER AND CONSOLE CONNECTOR

Fig.7: this power supply cable is made from a USB cable cut short, with a DC plug soldered onto the end. It plugs into a USB charger, which is a cheap and readily available source of regulated 5V. The unit can also be run from a USB power bank or the USB port of a computer. The wires inside the USB cable should be colour coded; solder the red wire to the inner conductor, the black wire to the outer barrel and cut short and insulate the white and green (USB signal) wires.



There's the old way, using a 455kHz generator and a 'scope to monitor the waveform (and lots of time!)... and the new way, using the touch-screen DDS to perform the alignment much more easily. Note that while the oscilloscope's vertical scale is showing peak voltage, the display on the *DDS Alignment Unit* has a logarithmic vertical scale (ie, it reads in dB) so the shape of the curve is different. However, they are effectively displaying the same thing.

only specified 47µF for VCAP in case tantalum capacitors are used.

When ceramic capacitors are used, 10µF is sufficient for all three. This has been a point of confusion for some constructors who have ordered kits.

Final assembly

The next job is to place the DDS module in the bottom of the case and mark and drill the four 3mm mounting holes, then attach it to the inside of the case using nylon machine screws and nuts, as shown in Fig.5.

This module should be mounted towards the right-hand end of the case, around 60mm from the end, with the output connector to the right.

The only other holes you need to drill are two in the right side of the case for the BNC sockets (10mm) and one in the left side for the DC power socket (8mm).

You can then mount those sockets and solder the extra components as shown in the wiring diagram, Fig.6.

The easiest way to do this is to trim the leads of the 10kΩ resistor and solder one to the central pin of the output socket.

One end of the 630V capacitor can be soldered to the PGA output of the AD9833 module before that module is installed in the case, then trim the remaining lead and solder it to the free end of the 10kΩ resistor.

The 4.7MΩ resistor can also be soldered directly to the centre pin of the input socket, and then a short wire is run back to pin 24 on the *BackPack* I/O header.

We made up a little plug-in board out of a piece of prototyping board, with the 1MΩ resistor onboard and a header for this wire to plug into so that we could easily remove it later if we needed to. You could solder the 1MΩ resistor directly between the pins to save time.

With the four extra components in place, all that's left to do is wire up the various connections using the jumper leads, as shown in Fig.6, plus the two wires to the DC socket.

Where you need to go from a header pin to a soldered connection, you can simply cut the DuPont socket off one end of the wire, strip it back and then solder it in place.

The other end can then just be plugged in; see the internal photo for more details.

Now double-check that you have wired up the DC socket with the correct polarity before powering the unit up because there's no protection against reverse polarity!

The easiest way to do this is to unplug the +5V connection from the *BackPack* board (check the silkscreen labelling to see which one this is) while leaving the earth connection attached.

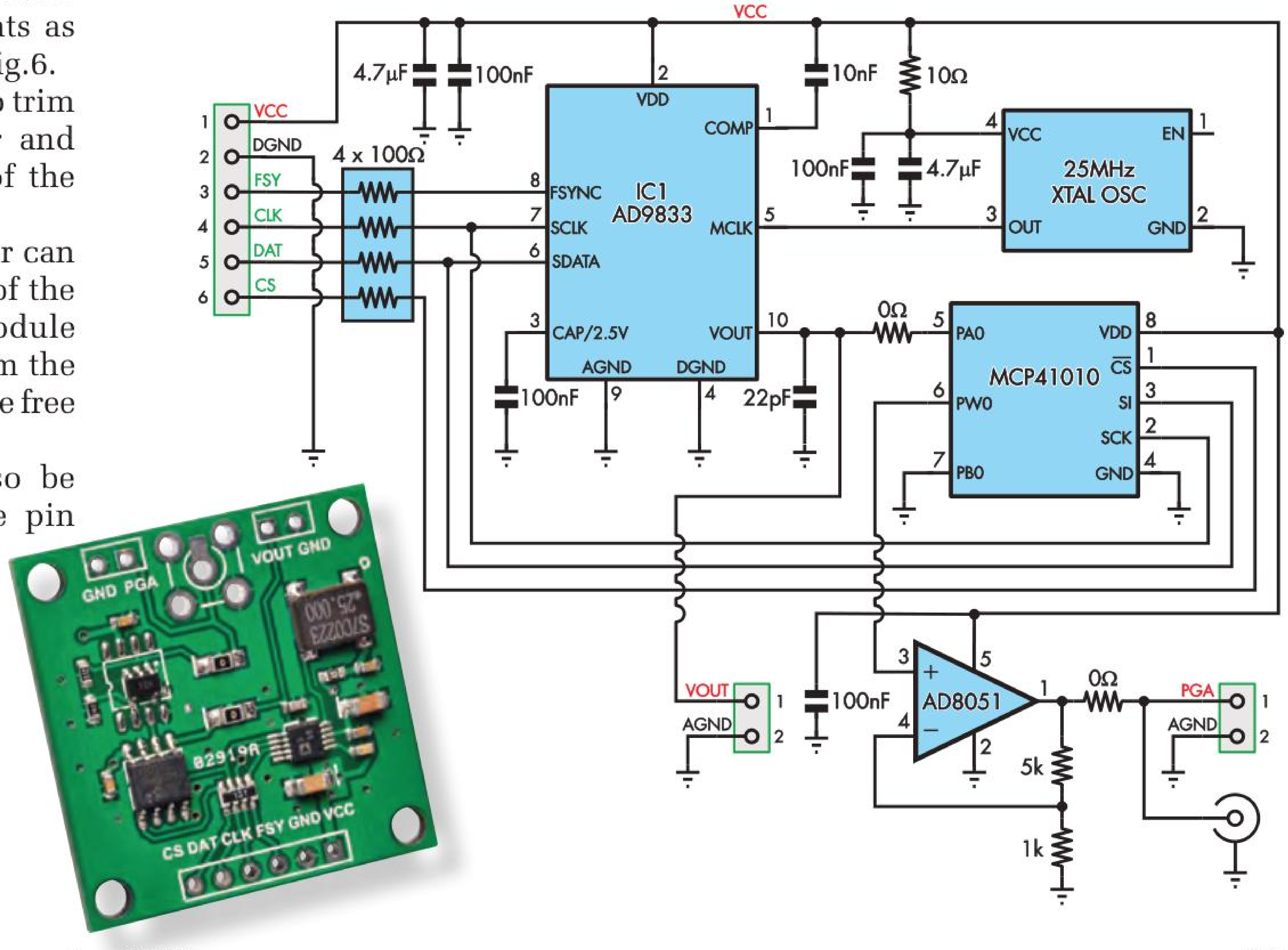
Apply power, then measure between the disconnected pin and the outer shield of one of the BNC sockets with your DMM, with the black lead to the BNC socket shields.

If you get a positive reading on the DMM, close to +5V, plug the cable back in and the unit should spring into life.

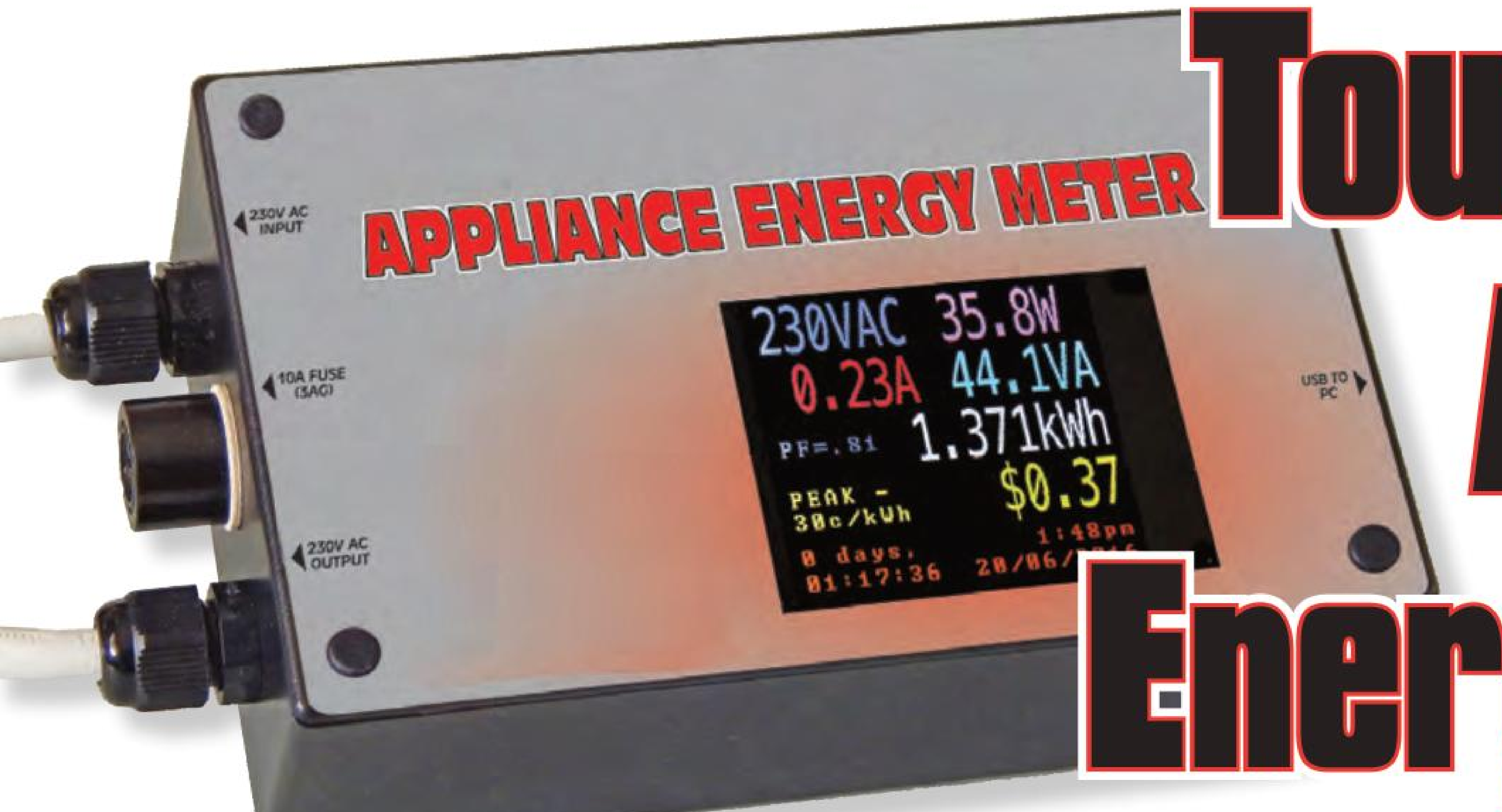
Once you've verified that it's all working, you can attach the laser-cut lid to the case with the supplied self-tapping screws and the unit is complete.

Note that as the lid is slightly thicker than the one originally supplied with the case, and doesn't have recesses for the screw heads, it's possible you may need to substitute longer screws; we find the ones supplied with UB3 boxes from Jaycar are just long enough.

Reproduced by arrangement
with SILICON CHIP
magazine 2018.
www.siliconchip.com.au



Reprinted from the April 2017 feature on the AD9833 module, this shows the circuit of the AD9833-based DDS module used in this project. The output is taken from the socket labelled PGA and AGND (lower right).



Touchscreen Appliance Energy Meter

Part 3 – Calibrating and Using it!

By JIM ROWE and NICHOLAS VINEN

In the last two months, we've described how our new *Touchscreen Appliance Energy Meter* works and how to put it together. Having finished assembling the unit, all that's left to do is to calibrate it and start using it.

Now you need to perform several calibration steps. These allow the unit to compensate for variations in the transformer and divider resistors used to monitor the mains voltage and the isolated current sensor used to measure the instantaneous current drawn by the load.

In a little more detail, as shown in Fig.2 of Part 1 in the July 2018 issue, the AC-coupled output of the transformer used to monitor the mains voltage is DC biased to around 2.5V by two 56kΩ resistors across the 5V supply rail.

However, the 5V rail from the AC/DC converter may not be exactly 5V and the resistors may not be exactly the same value, so we can't assume that the DC bias level is exactly 2.5V.

During the calibration procedure, the unit measures the average DC level of this signal and stores it so that it can be subtracted from future readings, to give a pure AC signal.

Note that while the mains waveform could have a slight DC offset due to asymmetrical current flow and improperly balanced phases, as we're measuring via a transformer, we have to ignore it.

Mains current calibration

The output of the isolated current sensor (IC4) has its own separate half-supply DC bias, obtained from a voltage divider inside the chip. So, calibration is performed with no load to allow the unit to measure the zero-current voltage level. This is also stored and subtracted from subsequent readings.

This bias exists because current can flow in either direction through the sensor, and thus its output can swing above or below the zero level, to indicate both the magnitude and polarity of the current.

This is important because we need to be able to distinguish in-phase current, which indicates power flowing from the mains into the load, and out-of-phase current, which indicates power flowing from the load back into the mains.

To calculate the true power drawn by the load, we subtract one from the other. Note that for purely reactive loads, such as capacitors connected across live and neutral, the result of this subtraction is zero, indicating that the power is purely reactive.

While measuring the current sensor's zero-level voltage, the unit also determines its RMS noise output, so that it can subtract this from future readings. Otherwise, it would look like current was flowing, even with no load.

Important!

Do read the note on minor design changes at the top of the second page in last month's article.

Calibration procedure

First, power the unit and wait at least 30 seconds for everything to settle (eg, coupling capacitors to charge).

You can judge this using the elapsed time in the lower-left corner of the device's display. Then touch this elapsed time display at the lower-left corner of the screen and you should see a 'Calib' button appear at the bottom (centre) of the screen (see Fig.8). Press this and the calibration screen will be displayed for a few seconds. It will then return to the main screen and after a second or two, the amps reading should drop to zero (power should be zero, too). This indicates that the unit has correctly calibrated the DC offset and base noise level from the current sensor.

Next, you need to manually adjust the voltage scale to give a correct mains voltage reading. All you need to do this is a mains-rated DMM.

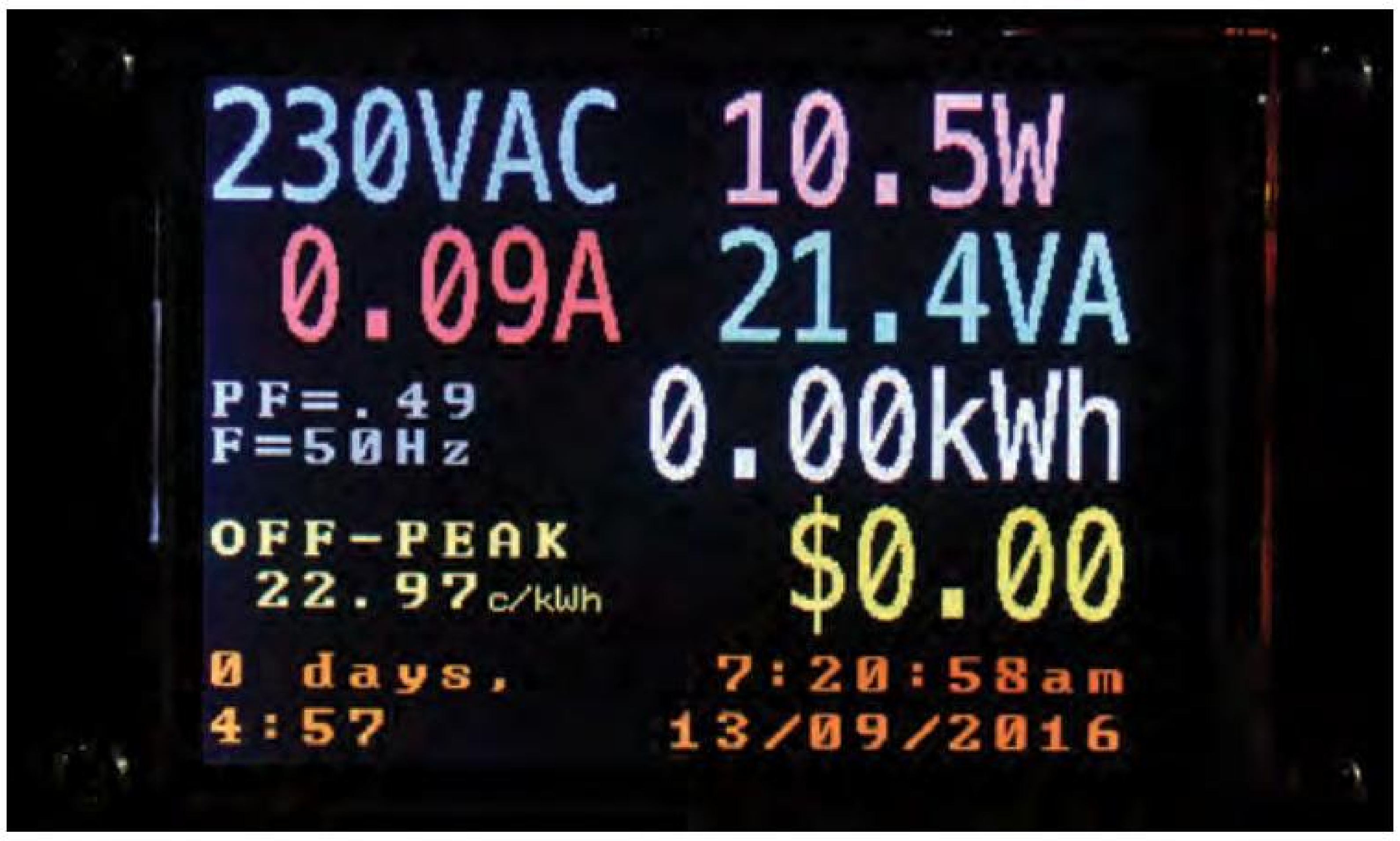
Set it to AC volts mode and if it isn't auto-ranging, set it to a suitable range for measuring mains (eg, up to 260VAC). After ensuring that you have suitably rated leads, push its prongs into the live and neutral sockets of a mains outlet. Make sure that there's no exposed metal that you could accidentally touch and also check that the probes won't fall out.

Now touch the lower-left corner of the screen again (the elapsed time display) and this time press the 'Diag' button. You should get voltage and current readings at the top of the screen, with + and – buttons to the right of each (see Fig.9).

Use these buttons to adjust the displayed voltage reading so that it matches the voltage on the DMM as closely as possible. You can now unplug the DMM from the socket.

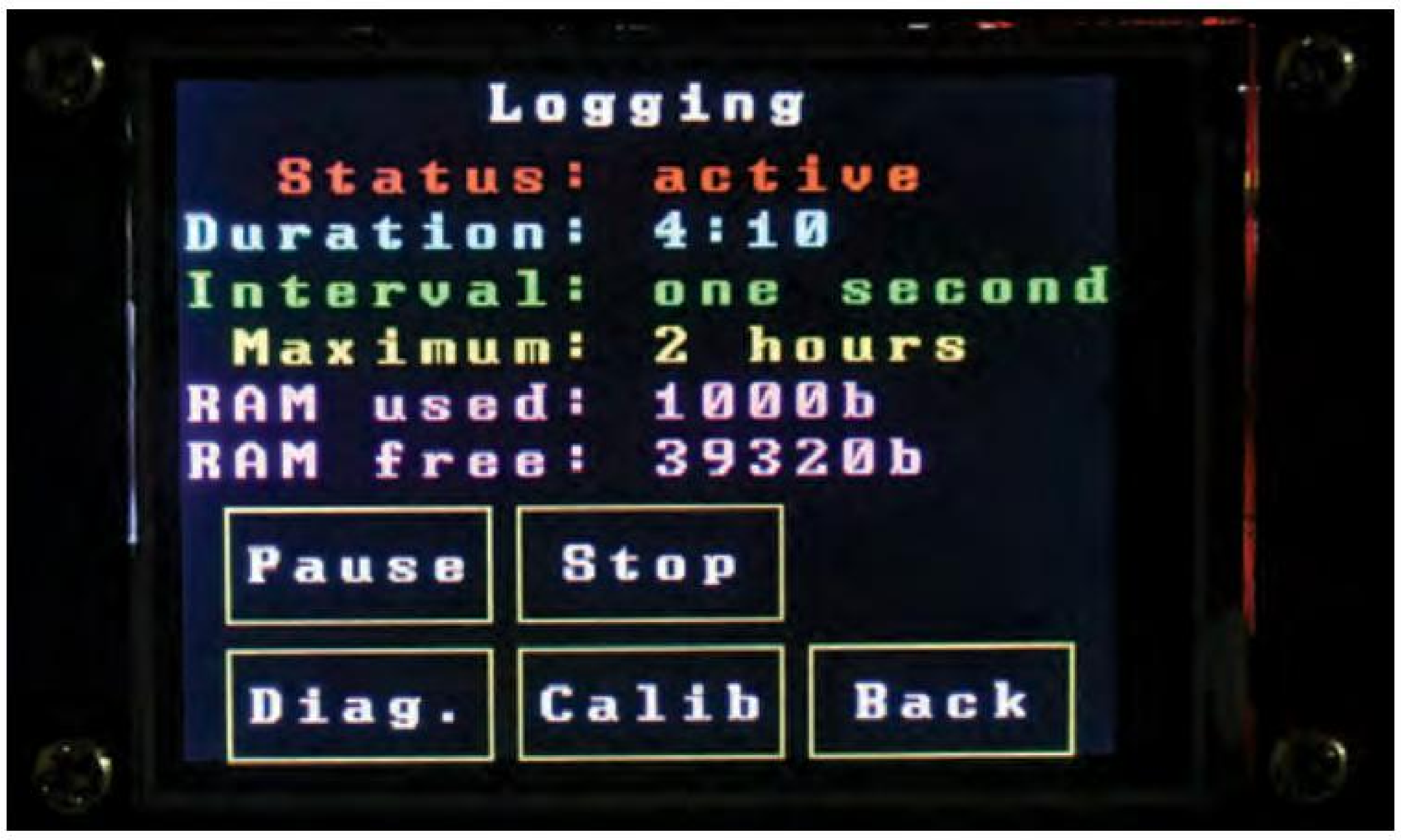
Current scale calibration

Now connect a device which will draw a small, fixed and easily determined amount of real power; for example, a



230VAC 10.5W
0.09A 21.4VA
PF=.49
F=50Hz 0.00kWh
OFF-PEAK 22.97c/kWh
$0.00
0 days, 4:57
7:20:58am 13/09/2016

Fig.7: the main screen which has been improved slightly since the prototype was revealed in the July issue. The main differences are the addition of the frequency read-out below the power factor and support for fractional cents/pence in the tariff, plus seconds display for the current time.



Logging
Status: active
Duration: 4:10
Interval: one second
Maximum: 2 hours
RAM used: 1000b
RAM free: 39320b

Fig.8: the logging status screen has also been improved since the first article. The same information is shown but there are now buttons to access the diagnostics screen and to perform automatic calibration. The button to dump logged data is not visible because you need to pause logging first.

small incandescent or halogen lamp. In a pinch, you could also use a desk fan or fluorescent lamp, but make sure it has a power consumption figure printed on it so you know what to expect. If you already have an accurate mains power meter, that's even better – use it to measure the power so that you have a calibration target for the new unit.

Now connect your test load to the *Energy Meter* and switch it on, then let it stabilise (it may need to warm up) and check the power reading. It will probably be close to the rated power, but maybe a little off. As you did when adjusting the mains voltage, use the + and – buttons next to the current reading in the diagnostic screen to make small adjustments to the current reading, then go back to the main screen and check the power reading. Continue adjusting until the power reading is very close to what you would expect.

If you'd like, you can now disconnect your test load and connect another small load, and verify that you get a reasonably accurate reading. Note that loads which draw very little power (eg, under 5W) could have a quite substantial measurement error and some loads such as plugpacks may even read zero when they are in fact drawing a watt or two. This is down to the limited resolution of the ADC and current sensor and there isn't a lot we can do about it.

You may also get some slightly inaccurate readings from loads with very low power factors. But generally, the unit should be quite accurate, within 1% or so of the actual reading, plus or minus a couple of watts.

Setting up tariffs

That's all you need to do to measure power consumption, but if you want to see how much an appliance is costing you to run, you will also need to program in your tariff(s) and if your home has a smart meter, the peak, off-peak and shoulder times. You will also need to set the current time and date. These all contribute to the unit being able to calculate the cost of power at any given time.

First, set the time and date by touching on the time/date display in the lower-right corner of the main screen. Type in the time, in 24-hour notation, with colons separating the hours, minutes and seconds. The seconds value is optional and the time will be set as soon as you press 'OK', so once you have entered the time value, you can wait until your clock rolls over to the next minute and then press that button. The value entered will be red if it is invalid or incomplete, or black if it is valid and complete.

Having set the time, enter the date in the same manner, in DD/MM/YY format. You can just press OK if you simply want to update the time and keep the current date.

Now that the time and date are set, press on the yellow tariff data to the left of the screen (initially, it will read 'OFF-PEAK 0.00c/kWh'). Now press on the 'Off-peak' text towards the bottom of the screen, type in the cost of power, in pence/cents per kilowatt-hour. You can use up to three decimal places. Press OK when finished, then press in the very upper-left corner to go back to the main screen.

If you don't have a smart meter, that is all you have to do because this tariff value is the default for situations where a conventional watt-hour meter is fitted. (Don't worry if you have an off-peak hotwater system as it is on a separate circuit in your house wiring).

Setting up time-of-day metering

Assuming you have a smart meter, you now need to set the peak and shoulder tariffs, using the same method. Then you will need to set the start and end times for the peak period during the week (ie, Monday through Friday). Refer to your electricity bill or electricity authority website if you don't have this information.

To set the peak times during the week, press on the text which says 'Weekday: N/A', just under where the peak tariff is displayed, near the top of the screen. Then, enter the peak start time in 24-hour format, with the hours and minutes separated by a colon and press OK. You will immediately be prompted to enter the end time, in the same format.

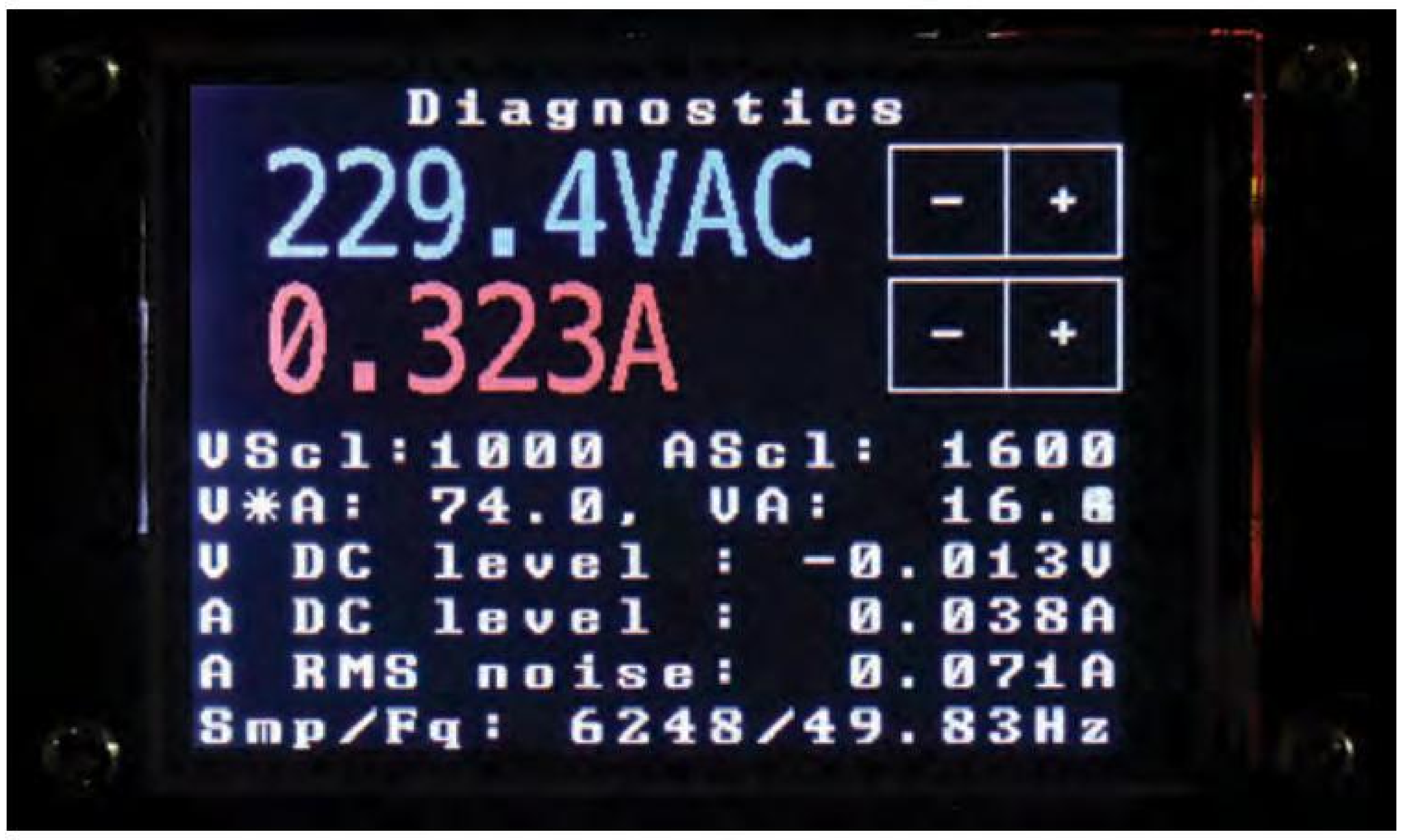
The unit has support for two peak periods, however you can only use this if your supplier has a separate morning and afternoon peak time. If not, simply press OK to go through the two following screens without entering any additional time values.

The peak time period should now be displayed below the peak tariff. If your supplier also has peak periods during the weekend, you can enter the start and end time by pressing on the line below which says 'Weekend: N/A' and using the same procedure as above. Otherwise, move on to setting up the shoulder period.

Many suppliers which have a peak period also have a 'shoulder' period before and after the peak period, where the cost of electricity is higher than it is off-peak but lower than during peak times. Assuming yours does too, you will need to set its start and end times just as you did for the peak period, but instead by pressing on the weekday and weekend lines below the Shoulder tariff.

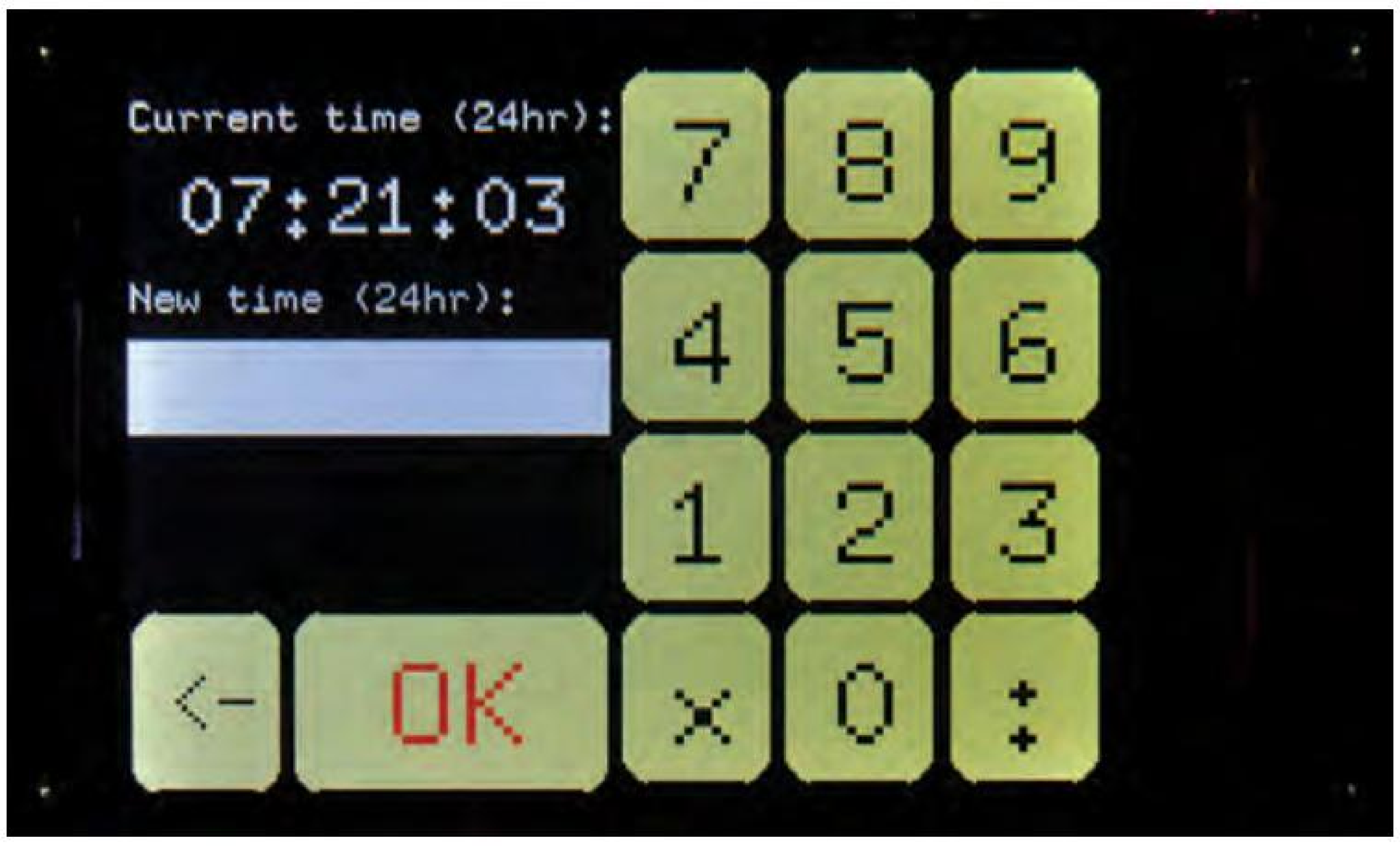
Note that it's OK for the peak and shoulder periods to overlap; indeed, they should. The peak tariff will override the shoulder tariff during those times when they are both active.

That's it, you can now go back to



```
Diagnostics
229.4VAC
0.323A
VScl:1000 AScl: 1600
V*A: 74.0, VA: 16.8
V DC level : -0.013V
A DC level :  0.038A
A RMS noise:  0.071A
Smp/Fq: 6248/49.83Hz
```

Fig.9: the diagnostic screen which shows the voltage and current readings with extra decimal places and allows fine adjustment of the scaling factors for both. It also displays the automatically calibrated calibration constants below, plus the sampling rate, measured frequency and pre-processing VA figures.



```
Current time (24hr):
07:21:03
New time (24hr):
```

Fig.10: the keypad displayed here allows you to update the current time and date as well as set the tariffs and various other tariff-related settings. In this case, we're setting the time and pressing OK without entering anything, which leaves it unchanged. The new time can be entered with or without seconds.

the main screen. The tariff data is automatically stored in non-volatile Flash memory and will survive a power outage (or simply unplugging and moving the unit).

Public holidays

While probably not critical, for the cost display to be truly accurate, we also need to take into account of the fact that public holidays are charged the same as weekends. For the unit to recognise this, it must know the dates of public holidays so you can program them in. If you don't, it won't normally make a big difference to cost calculations, so it's entirely up to you. But it only takes a few minutes.

To do this, acquire a list of the public holidays for the next couple of years, then touch on the area at the bottom of the tariff settings screen. You can then press on each blank public holiday space and enter the date in DD/MM/YY format. Enter as many or as few as required. Whenever the date matches one of these days, weekend rates will be applied. Touch right at the top of the screen to go back to the main tariff settings display.

Accumulating and logging data

Logging and accumulation of energy usage and cost begin automatically when the unit is plugged in. However, you can pause or stop and reset this data at any time. To do this, press on the time elapsed in the lower-left corner of the screen. The logging screen displays the current logging status, such as how much memory has been used and the maximum time that logging can continue with the current interval, as well as some buttons to control it (see Fig.8).

Pressing the 'pause' button will stop logging but retain all data so far. You can then resume or press the 'stop' button to clear the cumulative energy usage, cost and voltage/current/power logs.

Note that you can log data for up to two hours and 40 minutes with a one-second interval, up to 24 hours with a ten-second interval and up to one week with a one-minute interval but you can only change the interval when logging is stopped (ie, no data is stored). To do so, simply press on the 'Interval:' line on the logging screen.

While paused, you also have the option to dump the logged data to your PC via the USB interface. This can be done with the mains still connected. In fact, if the unit loses power, this logged data will be lost, so you will need to keep the mains power plugged in, at least until you've connected the USB interface.

Once the USB serial port has been recognised by your PC, fire up a terminal program and open that port with the correct baud rate (normally 38,400). Next, set up the terminal program to capture data from that serial port to a file. You can then press the 'Dump' button on the screen and the data will be output in CSV format, as follows:

```
SILICON CHIP Appliance Energy Meter log
at 11:04:37 09/09/2016
num,seconds,time,v,a,va,power,pf
1,0,00:00,237,0.221,52.4,12.3,0.235
2,10,00:10,235,0.219,51.5,12.7,0.247
...
```

It may take some time to off-load all this data at 38kbaud, depending on how long you have been logging. This data can be saved in a CSV file and opened in a spreadsheet program. The columns are as follows:

1. Record number, starting at one for the first row of data.
2. Number of seconds since logging began. Starts with zero and increments by one, 10 or 60 depending on the logging interval.
3. Time since logging began, in mm:ss or hh:mm format, depending on how long logging has been going.
4. Average mains RMS voltage for the logged interval.
5. Average mains RMS current for the logged interval.
6. Product of #4 and #5, ie, average VA for the logged interval.
7. Average real power for the logged interval.
8. Average power factor for the logged interval (ie, #7 divided by #6).

When finished, press the 'Back' button to return to the main screen.

Note that while logged data is lost if the unit's power is removed, the accumulated power usage and cost information, shown on the main screen, is stored in the EEPROM once per minute and the last saved data is restored at power-on. This data is only reset when logging is stopped.

Plotting data on the unit

The data stored in RAM which can be exported to a PC can also be used to produce various plots on the *Meter's* touchscreen. However, due to limited screen space (and program space), you can only plot one measurement at a time.

Simply touch on one of the following items on the main screen to draw a graph of the data collected so far: voltage, current, power, VA or power factor. Initially, a line graph will be drawn, showing the variation in that parameter over time. You can change the plot duration between one hour, one day and one week by touching on the duration legend below the graph. Note that if the unit has insufficient data to show the selected duration, it will simply show what it has so far.

The vertical axis of the graph is automatically scaled to fit the data collected so far. The horizontal axis has the latest measured value at right and the oldest data at far left. Note that depending on how long the unit has

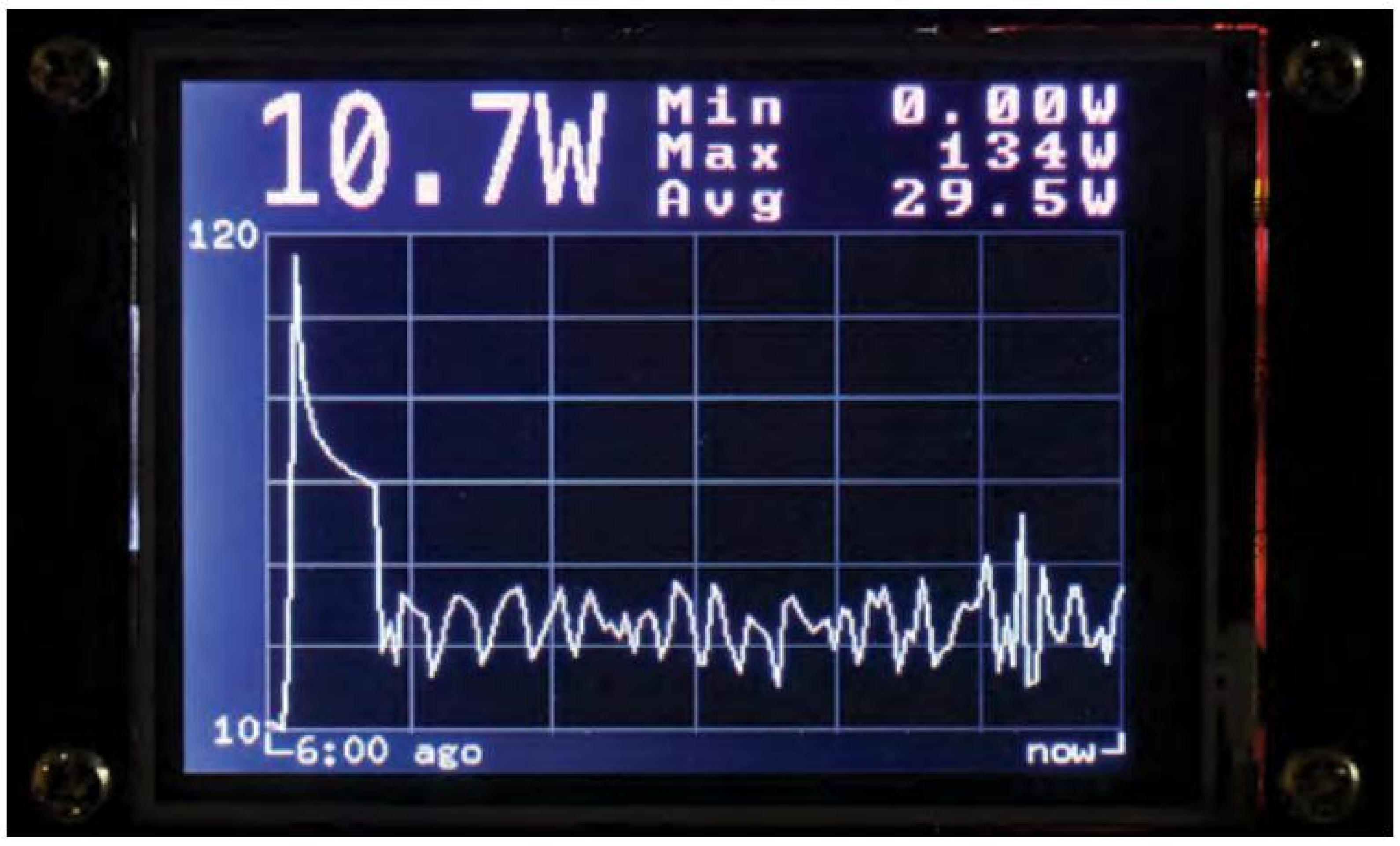


Fig.11: power usage plot for a soldering iron. The iron was switched on around five minutes ago and you can see the large power draw as it warms up initially, followed by the consumption jumping up and down as the element is switched on for brief periods to keep it warm.

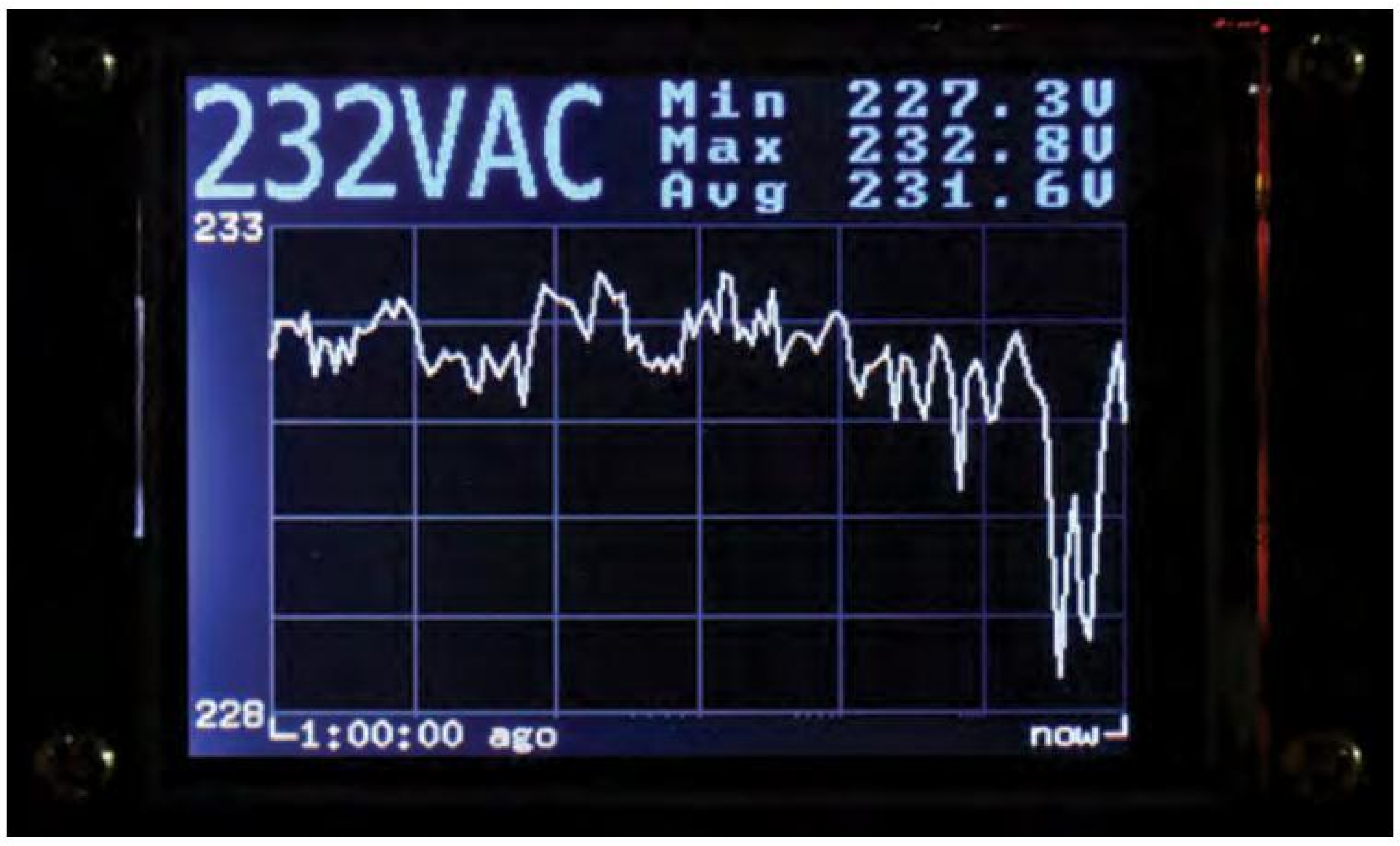


Fig.12: plot of the mains voltage which shows how it varies over a one-hour period. Depending on the location and time of day, the voltage can vary far more dramatically than this. Even so, we can see it varying by more than 1% (2.3V) in a relatively short period of just 30 seconds or so.

been running, it can take some time for it to average all the data required to plot the graph, so be patient.

The unit can also display the same data in a histogram. Simply press in the middle of the graph to switch to histogram mode. The data is automatically allocated to ten 'bins' which span the range of data collected and their height indicates the proportion of values measured which fit into those 'bins' (see Fig.13). Press on the middle of the graph again to go back to the main screen. (This is the only way to get out of the graph display.)

Extrapolating power consumption and cost

During logging, the total power consumption and accumulated cost on the main screen are continuously updated (once per second). They will continue to increase even if the logging RAM is full, indefinitely.

If you want to see how much an appliance is costing you on average, or its average power usage, connect it to the *Meter* and let it run for a sufficient period for it to experience representative power usage. In some cases (for example, a refrigerator or air conditioner), this may take one or two days.

At the end of this period, simply touch on the power consumption or cost figure on the main screen. The unit will divide the figure by the amount of

Developing the two critical CFUNCTIONs

While the GUI code is mostly written in BASIC, we had to write two sections of the program in C. The first is the part which queries the ADC and performs averaging, power calculations and zero crossing/frequency detection. This needed to be written in C so that it was fast enough both to be run thousands of times per second while still allowing enough free CPU resources to handle screen updates, and so that it could run constantly in the background to avoid missing any voltage, current or power samples.

The second is the part of the code which calculates the current tariff based on the time, date and configuration data. This was originally written in BASIC, however, it used too much RAM. This was especially problematic because the very inner-most function which reads and stores power data must call it in order to keep the running cost up to date (based on the current tariff). Rewriting this code in C caused it to use up more Flash memory (due to the way CFUNCTIONs are stored) but significantly less RAM and solved a long-running problem with the unit crashing due to lack of memory. It's also a lot faster than the equivalent BASIC code.

Essentially, what this second function does is calculate the day of the week based on the date, then if it is a weekday, it checks to see if the date matches any of the public holidays programmed into the unit. Once it knows whether to use the weekday or weekend tariffs, it figures out the current tariff based on the time.

The other CFUNCTION is significantly more complex. While it's a single function, it performs multiple duties. The first one is to set up the hardware sampling timer (TIMER1) and the internal data structures used to keep track of items such as voltage, current and power. As soon as TIMER1 is set up, the interrupt handler runs several thousand times per second and this alternately samples the voltage and current.

After each pair of samples has been completed, it then updates the internal RMS voltage, current, VA and power variables and checks to see if a zero crossing has occurred. If so, it increments the zero crossing count and transfers the accumulated data into a second area of RAM, so that all averages are performed on full multiples of half-cycles of data (to prevent readings from varying depending on which point in the half-cycle the data is read).

The BASIC software can then call the same CFUNCTION with a different set of parameters to read out these internal registers and get at the accumulated data. When this data is read, interrupts are disabled and it is cleared, so that the next ADC interrupt will start fresh, collecting the next set of data.

The number of zero crossings detected per time period is used to calculate the mains frequency along with the real-time clock and the Micromite's internal millisecond timer.

Finally, this CFUNCTION also provides calibration functions, ie, the ability to read and write the registers which define the voltage and current DC offset levels, as well as compute these levels when no load is connected. Once set, the calibration levels are used by the sampling code to improve the accuracy of the readings. Some calibration functions, specifically the relationship between measured voltage and actual mains voltage and current, as well as dealing with noise from the current sensor, are performed solely by the BASIC code.

Those who are curious can download both the BASIC and C source code from the *EPE* website and see the full details.

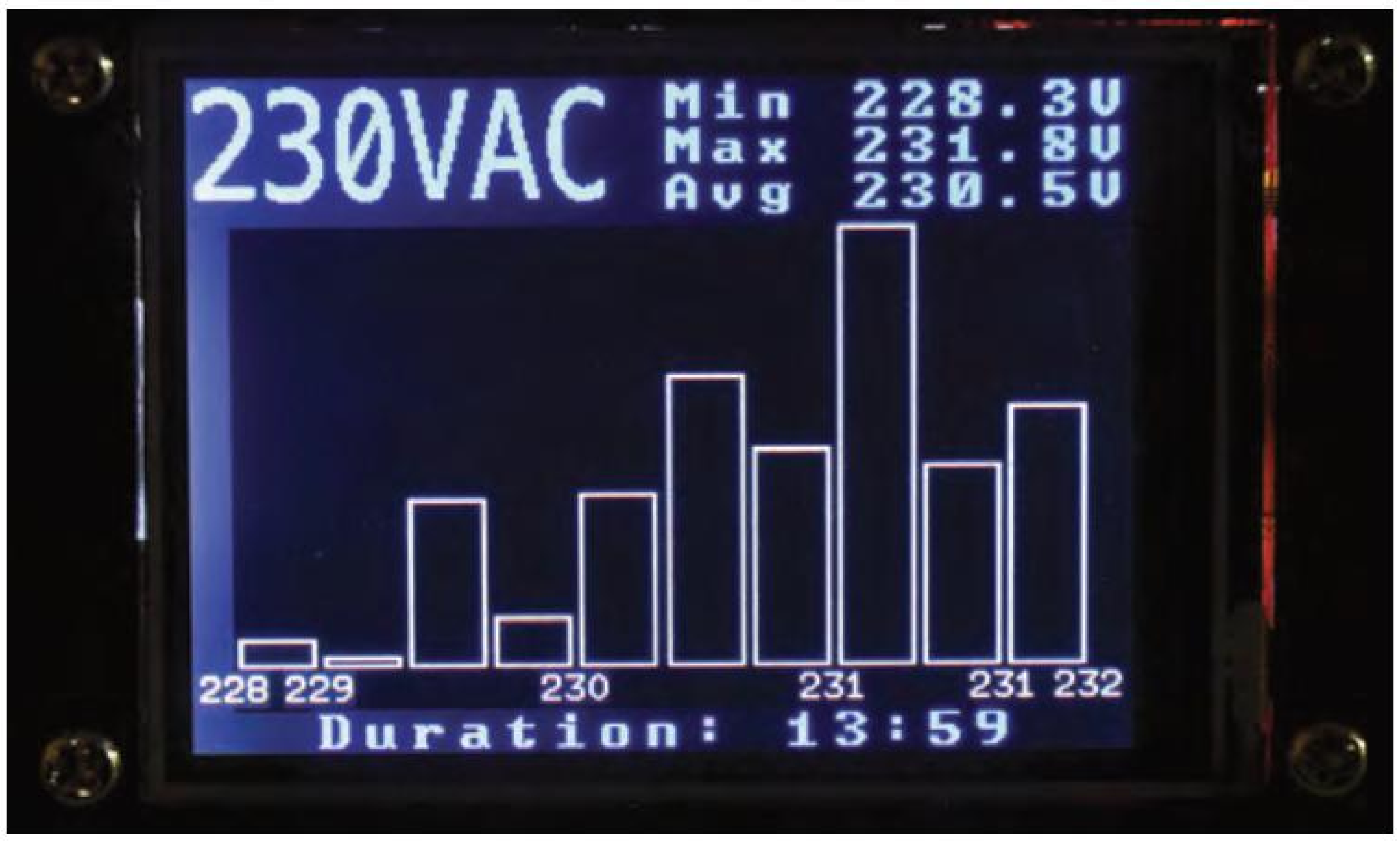


Fig.13: histogram plot of mains voltage. This gives you a good idea of which voltages the mains sits at most of the time relative to outliers. Note that the X-axis labels are rounded to the nearest volt, while the data has sub-volt resolution.

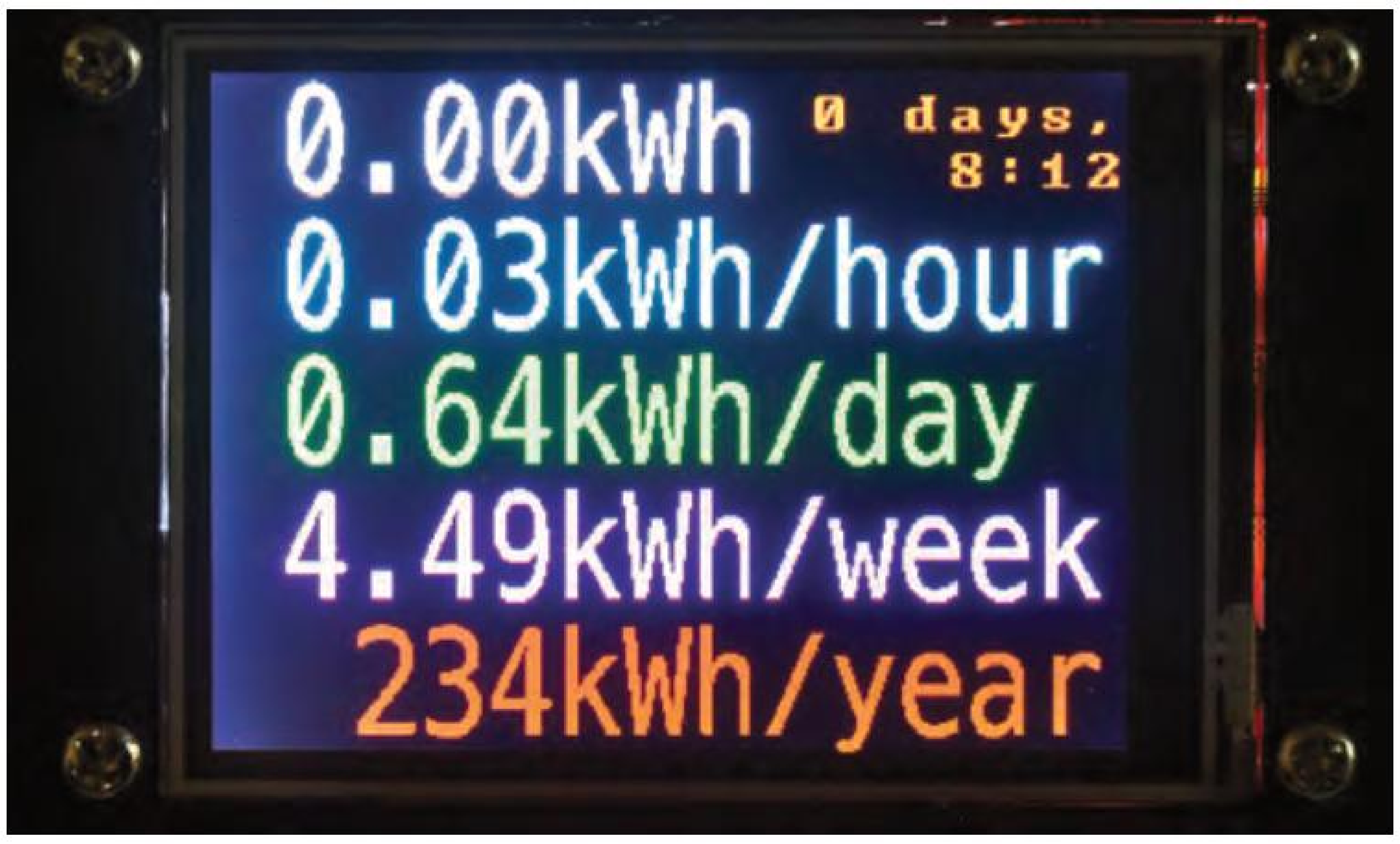


Fig.14: extrapolated energy usage involved in running a temperature-controlled soldering iron, based on around eight minutes of data. You don't normally leave a soldering iron on all the time but if you did, this shows just how much power it would use.

time it has spent monitoring that load, then extrapolate the energy usage/cost out to the following periods: one hour, one day, one week, one month and one year. This will tell you the energy usage/cost for running that appliance over those periods, assuming that the energy usage continues at the same rate (see Fig.14).

With something like an air conditioner, you will have to keep in mind that if you are measuring during summer or winter, the yearly usage will be overestimated (since you won't need the same amount of cooling or heating year-round). For heaters, the same is true, but in reverse. And refrigerator energy usage is likely to vary significantly with the season too.

Conclusion

The easiest way to become familiar with the functions of this device is probably to set it up and 'play'. For those constructors who may wish for features that we didn't have room for, feel free to download the BASIC source code and add your own. However, keep in mind that you will probably need to remove some of the existing features to make room.

Reproduced by arrangement
with SILICON CHIP
magazine 2018.
www.siliconchip.com.au

Micromite parts

We strongly recommend you make **micromite.org** your first port of call when shopping for all Micromite project components. Phil Boyce, who runs micromite.org, can supply kits, programmed ICs, PCBs and many of the sensors and other devices mentioned in recent articles – in fact, just about anything you could want for your Micromite endeavours. Phil works closely with Geoff Graham and is knowledgeable about the whole series of Micromite microcontrollers.

MICROMITE
SIMPLE · INTERACTIVE · FUN

COMPETITION

This month, ***EPE*** and **micromite.org** are giving you another chance to win a fully assembled 28-pin Micromite BackPack module, complete with 2.8" touchscreen. For details about this powerful, yet compact module, turn to page 12 in the May 2017 edition of ***EPE***.

To enter, simply send an email to **epe@micromite.org** with the email subject as: **EM3 Raffle**

Please ensure you email before the closing date: 31 August 2018

The name of the lucky winner will be published in a future edition of *EPE*.

Look out for future competitions to win other fantastic Micromite products.

Good Luck!

WIN A Micromite BackPack!

T&Cs
1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid shipping address to which their prize will be shipped
5. UK winners will have their prize sent via Royal Mail's Special Delivery service
6. Overseas winners will have their prize sent by Royal Mail's International Tracked & Insured service

STORE YOUR BACK ISSUES ON CD-ROMS

Order on-line from
www.epemag.com (go to the UK store)
or by phone, fax, email or post

ONLY
£16.45
(£29.95 FOR 5 YEAR)
each including VAT and p&p

EPE Online
Back Issues
Vol 6 ☐
Vol 7 ☐
Vol 8 ☐
Vol 9 ☐
Vol 11 ☐
Vol 12 ☑
Vol 13 ☐
Vol 14 ☐
Vol 15 ☐
browser to open 0000.htm
2005 TechBites Interactive Inc.
Wimborne Publishing Ltd.

VOL 1: **BACK ISSUES** – January 1999 to June 1999
Plus some bonus material from Nov and Dec 1998
VOL 2: **BACK ISSUES** – July 1999 to December 1999
VOL 3: **BACK ISSUES** – January 2000 to June 2000
VOL 4: **BACK ISSUES** – July 2000 to December 2000
VOL 5: **BACK ISSUES** – January 2001 to June 2001
VOL 6: **BACK ISSUES** – July 2001 to December 2001
VOL 7: **BACK ISSUES** – January 2002 to June 2002
VOL 8: **BACK ISSUES** – July 2002 to December 2002
VOL 9: **BACK ISSUES** – January 2003 to June 2003
VOL 10: **BACK ISSUES** – July 2003 to December 2003
VOL 11: **BACK ISSUES** – January 2004 to June 2004
VOL 12: **BACK ISSUES** – July 2004 to December 2004
VOL 13: **BACK ISSUES** – January 2005 to June 2005
VOL 14: **BACK ISSUES** – July 2005 to December 2005
VOL 15: **BACK ISSUES** – January 2006 to June 2006
VOL 16: **BACK ISSUES** – July 2006 to December 2006
VOL 17: **BACK ISSUES** – January 2007 to June 2007
VOL 18: **BACK ISSUES** – July 2007 to December 2007
VOL 19: **BACK ISSUES** – January 2008 to June 2008
VOL 20: **BACK ISSUES** – July 2008 to December 2008
VOL 21: **BACK ISSUES** – January 2009 to June 2009
VOL 22: **BACK ISSUES** – July 2009 to December 2009
VOL 23: **BACK ISSUES** – January 2010 to June 2010
VOL 24: **BACK ISSUES** – July 2010 to December 2010
VOL 25: **BACK ISSUES** – January 2011 to June 2011
VOL 26: **BACK ISSUES** – July 2011 to December 2011
VOL 27: **BACK ISSUES** – January 2012 to June 2012
VOL 28: **BACK ISSUES** – July 2012 to December 2012
VOL 29: **BACK ISSUES** – January 2013 to June 2013
VOL 30: **BACK ISSUES** – July 2013 to December 2013
VOL 31: **BACK ISSUES** – January 2014 to June 2014
VOL 32: **BACK ISSUES** – July 2014 to December 2014
VOL 33: **BACK ISSUES** – January 2015 to June 2015
VOL 34: **BACK ISSUES** – July 2015 to December 2015
VOL 35: **BACK ISSUES** – January 2016 to June 2016
VOL 36: **BACK ISSUES** – July 2016 to December 2016
VOL 37: **BACK ISSUES** – January 2017 to June 2017

NEW Vol.38

VOL 38: **BACK ISSUES** –
July 2017 to December 2017

FIVE YEAR DVD/CD-ROMs
NOW AVAILABLE

FIVE YEAR CD/DVD-ROMs

No.1 – Jan '03 to Dec '07
No.2 – Jan '04 to Dec '08
No.3 – Jan '05 to Dec '09
No.4 – Jan '06 to Dec '10
No.5 – Jan '07 to Dec '11
No.6 – Jan '08 to Dec '12
No.7 – Jan '09 to Dec '13
No.8 – Jan '10 to Dec '14
No.9 – Jan '11 to Dec '15
No.10 – Jan '12 to Dec '16

NEW Vol.11

No.11 – Jan '13 to Dec '17

NOTE: These DVD/CD-ROMs are suitable for use on any PC with a DVD/CD-ROM drive. They require Adobe Acrobat Reader (available free from the Internet – **www.adobe.com/acrobat**)

WHAT IS INCLUDED

All volumes include the *EPE Online* content of every listed issue. **Please note that we are unable to answer technical queries or provide data on articles that are more than five years old. Please also ensure that all components are still available before commencing construction of a project from a back issue.**

BACK ISSUES DVD/CD-ROM ORDER FORM

Please send me the following Back Issue DVD/CD-ROMs.

Volume Numbers:. . . . .

. . . .

Price £16.45 each, £29.95 for Five Year DVD/CD-ROMs – includes postage to anywhere in the world.

Name . . . .

Address . . . .

. . . .

Post Code. . . . .

☐ I enclose cheque/P.O./bank draft to the value of £ . . . .

☐ please charge my Visa/Mastercard £ . . . .

Card No. . . . .

Card Security Code . . . . (The last 3 digits on or just under the signature strip)

Valid From . . . . Expiry Date . . . .

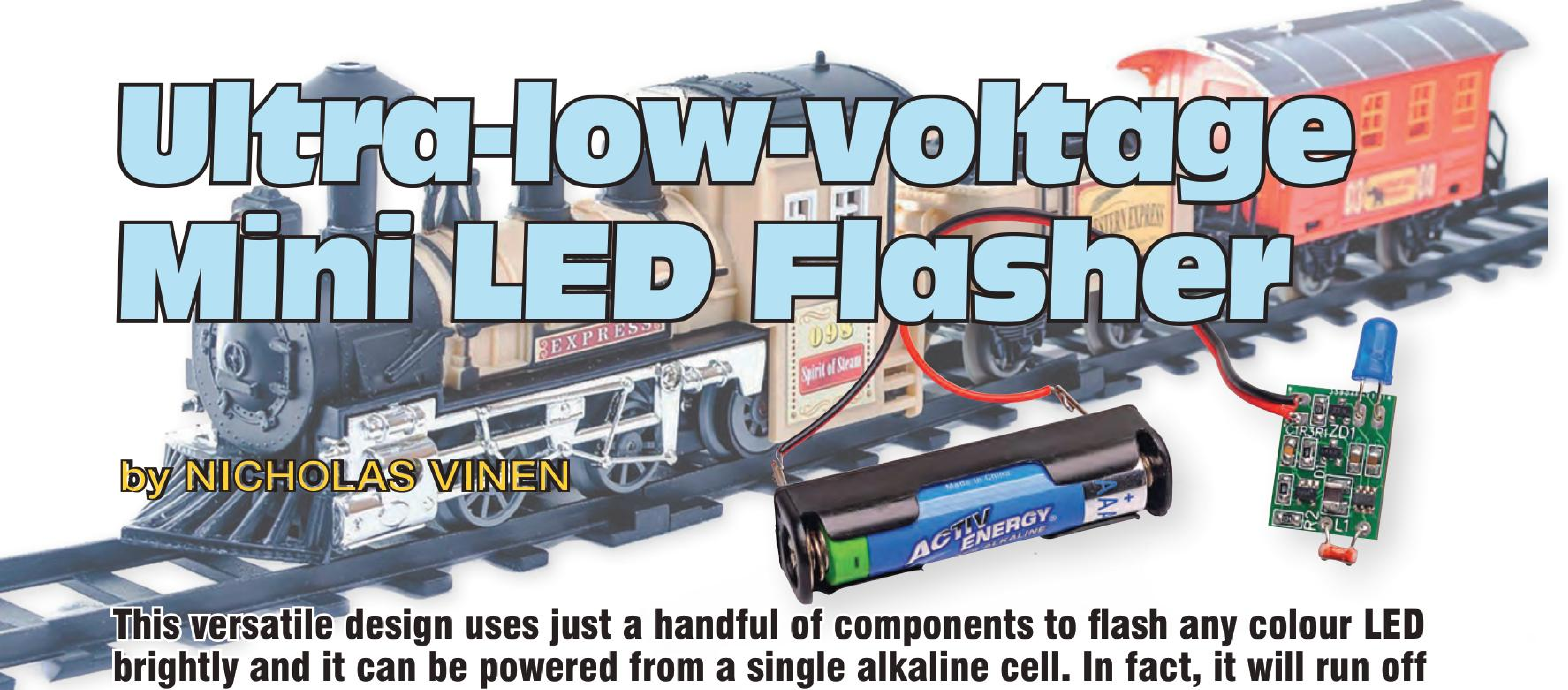
SEND TO: **Everyday Practical Electronics,**
Wimborne Publishing Ltd., 113 Lynwood Drive, Merley,
Wimborne, Dorset BH21 1UU.

Tel: 01202 880299. Fax: 01202 843233.
E-mail: fay.kearn@wimborne.co.uk

Payments must be by card or in £ Sterling – cheque or bank draft drawn on a UK bank.

Normally posted within seven days of receipt of order.

Ultra-low-voltage Mini LED Flasher



by NICHOLAS VINEN

This versatile design uses just a handful of components to flash any colour LED brightly and it can be powered from a single alkaline cell. In fact, it will run off any supply from 0.8V to 3.3V and consumes very little power when the LED is off. It's built on a tiny board, so it will fit just about anywhere and incorporates ambient-light monitoring to switch the LED off during the day.

We have presented simple LED flashers in the past, but this one is a little different. While it uses just a handful of parts, it's able to drive the LED with a current of up to 50mA, to provide a very bright flash, even when running from a 1.5V cell.

The complete module is just 15 × 19 × 4mm, so it can fit inside toy cars, model railway locomotives and other tight spots.

The LED current is set by a resistor and the maximum setting produces an almost blinding flash when used with a high-brightness LED. But it consumes just a few microamps the rest of the time for a low average current draw and thus excellent battery life.

It also incorporates a feature we previously introduced in a recent LED flasher design, an optional light-dependent resistor (LDR) which turns the flasher off during the day or when bright indoor lighting is switched on, to avoid wasting energy and thus further extening battery life.

While this design does rely on a few small SMDs to build such a compact module, they are not especially difficult to solder and do not require any special tools.

You just need a temperature-controlled soldering iron, flux paste, solder wick, magnifying lamp (or equivalent) and reasonably steady hands. And although the ICs are relatively specialised, they are neither expensive nor difficult to get.

We will be offering a PCB, but before we get into the construction, let's look at how it works.

Circuit description

The complete circuit is shown in Fig.1 and consists of two main parts, an oscillator which determines the LED flash frequency and duty cycle (at lower left) and the switchmode regulator in the middle, which boosts the supply voltage up to that required to run the LED, and regulates the current through it. Let's look at the oscillator first.

This is based around IC1, an SN74AUP1G14DBVR schmitt trigger inverter. The part number is a mouthful, but you may notice the 74 and the 14 in there, indicating that it's similar to a 74HC14 IC, but with just a single inverter instead of six.

It's designed to run from between 0.8V and 3.6V and has a static current drain of less than 1µA, although its dynamic power consumption in this circuit is higher with the current at around 10µA. This needs to be relatively low because the oscillator is constantly powered from the unregulated supply (typically a single cell at around 1-1.5V).

It oscillates due to positive feedback from its output to its input, mainly via the 10MΩ resistor and the rate of oscillation is determined by this in combination with C1, which forms an RC low-pass filter.

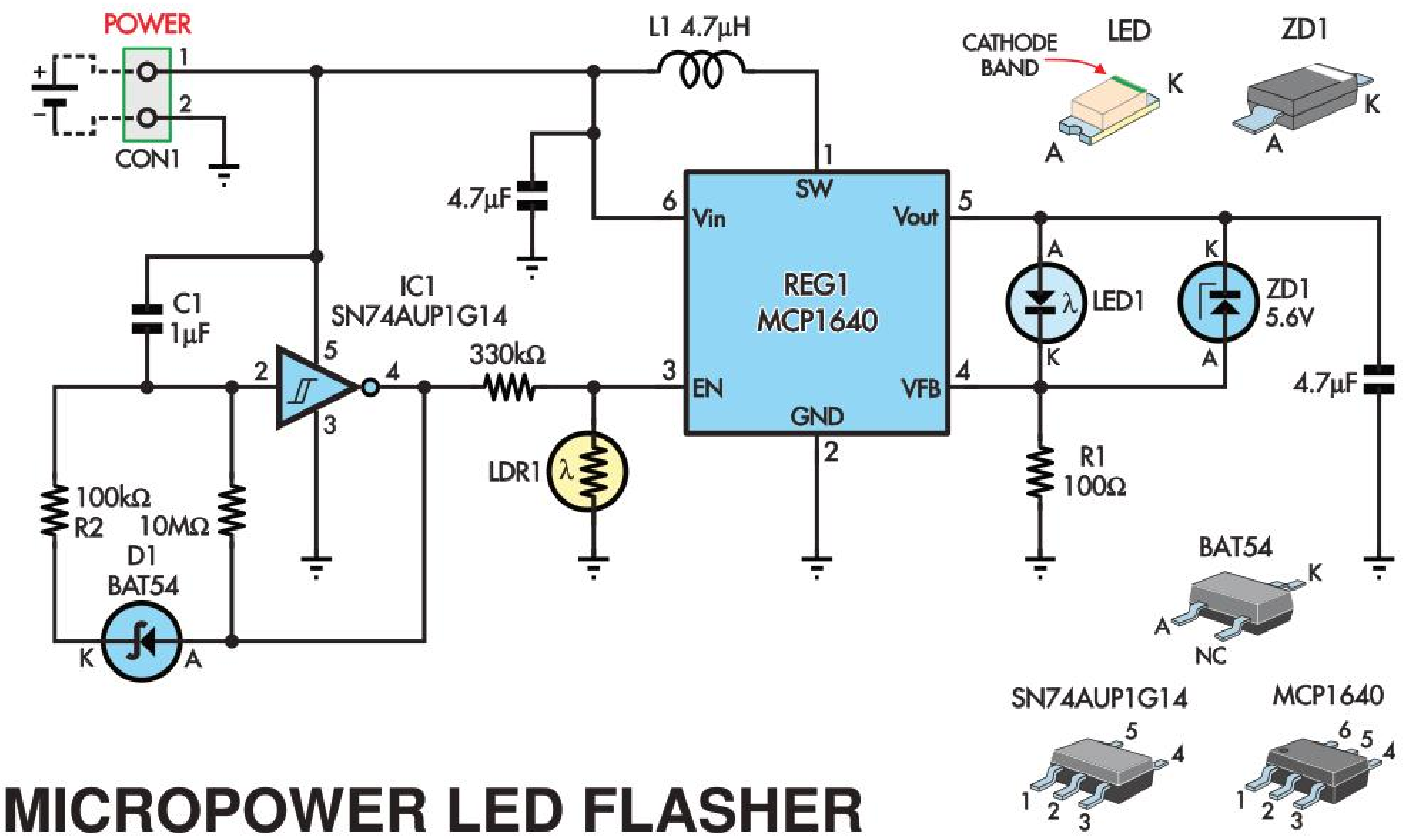
When IC1's output is high, C1 discharges (ie, the voltage at pin 2 increases) until the voltage at pin 2 reaches its positive-going threshold and output pin 4 goes low. C1 then charges through the 10MΩ resistor until the pin 2 voltage reaches the negative-going threshold and the output at pin 4 switches high again.

The difference between the two thresholds is known as the hysteresis voltage and for IC1 this can be calculated as 70mV + (V_{CC} – 0.8) ÷ 3.

Unfortunately, since the hysteresis varies with V_{CC}, the frequency will increase as the supply voltage drops

Features and specifications

Supply voltage: 0.8 – 3.3V
LED current: 12mA as presented; can be set to 1-50mA
Supply current: 4mA average as presented, 50mA peak (8% duty cycle)
Standby current: ~20µA average when not flashing
Battery life: ~10 days with button cell; ~25 days with alkaline AAA; 50+ days with alkaline AA (10 hours flashing per day)
LED driving efficiency: ~60%
LED forward voltage: 1-3.6V
LED flash rate: 0.1-10Hz, as set by C1; increases by up to 50% with reduced supply voltage
LED duty cycle: 8% as presented; can be set to 1%-25% by changing R2
Size and weight (not including cell/battery): 15 x 19 x 4mm, <5g



MICROPOWER LED FLASHER

Fig.1: complete circuit for the micropower *LED Flasher*. The circuit is based around an SN74 schmitt trigger inverter (IC1) and an MCP1640 low-voltage boost regulator (REG1) with an integrated load disconnect switch.

(eg, due to the cell discharging). To give an idea of the magnitude of the effect, if the flash rate is 1Hz at 1.5V, it will be around 1.5Hz at 1V.

Schottky diode D1 and its series 100kΩ resistor (R2) change the duty cycle of the square wave at pin 4 of IC1. Normally, it would be close to 50%, but this would result in visibly long LED flashes and waste power. When pin 4 goes high, D1 is forward-biased, so C1 discharges via R2, speeding up its discharge rate and thus reducing the time that pin 4 is high.

The values shown set the duty cycle to around 8%. You might think it would be 1%, but remember that D1's forward voltage is a significant fraction of the supply voltage. Despite this low duty cycle, the LED flashes appear very bright on our prototype.

The opposite end of timing capacitor C1 is connected to the positive power rail so that input pin 2 of IC1 is initially high and thus its output is low and the boost regulator (REG1) and LED1 are disabled. C1 needs a couple of seconds to charge before the oscillator begins to operate, and it's best for REG1 to be off during this time.

The oscillator output at pin 4 of IC1 goes through a voltage divider consisting of a 330kΩ fixed resistor and the LDR, which has a dark resistance in excess of 1MΩ and a light resistance below 50kΩ. Thus, in the dark, when the output of IC1 is high, the voltage applied to pin 3 of REG1 is close to V_{CC}, since the resistance in the bottom leg of the divider is so high.

But in relatively bright light, the ~50kΩ resistance of the LDR shunts most of the current from the output of IC1, reducing the voltage at pin 3 of REG1 by 0.3V and this is insufficient to switch REG1 on. So if the ambient light level is high, REG1 is off and the LED won't flash.

The only power consumption in this condition is that of IC1, the current required to charge/discharge C1 and the current through the 330kΩ/LDR divider, which only flows when the output of IC1 is high. This averages to around 20µA (see Fig.6). Note that if you want the LED to flash constantly, all you need to do is omit the LDR so that the output of IC1 reaches REG1 without attenuation.

When pin 3 of REG1 is high, the IC is enabled. REG1 is a somewhat unusual boost regulator in that when it is disabled, the current path from input to output is cut off entirely. This is very useful since otherwise the supply voltage may be high enough to cause the LED to light even when it should be off. But REG1's internal switch ensures that there is no path for current to flow.

Fig.2 shows the internal block diagram of the MCP1640 boost regulator. In brief, what it does is pulse pin 1 (SW) low at a frequency of around 500kHz with a controlled duty cycle, so that the interruption of current through inductor L1 causes an increase in the voltage at this pin, compared to the input at pin 6. Current then flows from L1 through REG1 and out of pin 5, charging the 4.7µF output capacitor and also driving current through LED1.

The current through LED1 and R1 rises until it reaches approximately 12mA, at which point the voltage across R1 reaches about 1.21V. Now, REG1 throttles back the duty cycle of its internal switch to maintain this current level. This continues until the pin 3 enable (EN) input goes low and the 4.7µF output capacitor discharges through LED1 and R1.

In more detail, when REG1's internal transistor from pin 1 to pin 2 (ground) is switched on, current starts to flow through SMD inductor L1, increasing in a smooth manner. As the current increases, L1's magnetic field charges up. When this internal switch turns off, L1's magnetic field continues to drive current from the supply at pin 6 through to pin 1. As a result, the voltage at pin 1 rises.

Once the voltage at pin 1 rises above that at V_{OUT} (pin 5), the other transistor in REG1 switches on to allow current to flow from pin 1 to pin 5. This charges up the 4.7µF capacitor from pin 5 to ground and, depending on whether the voltage is sufficient to cause LED1 to conduct, some or all of this current causes it to light up.

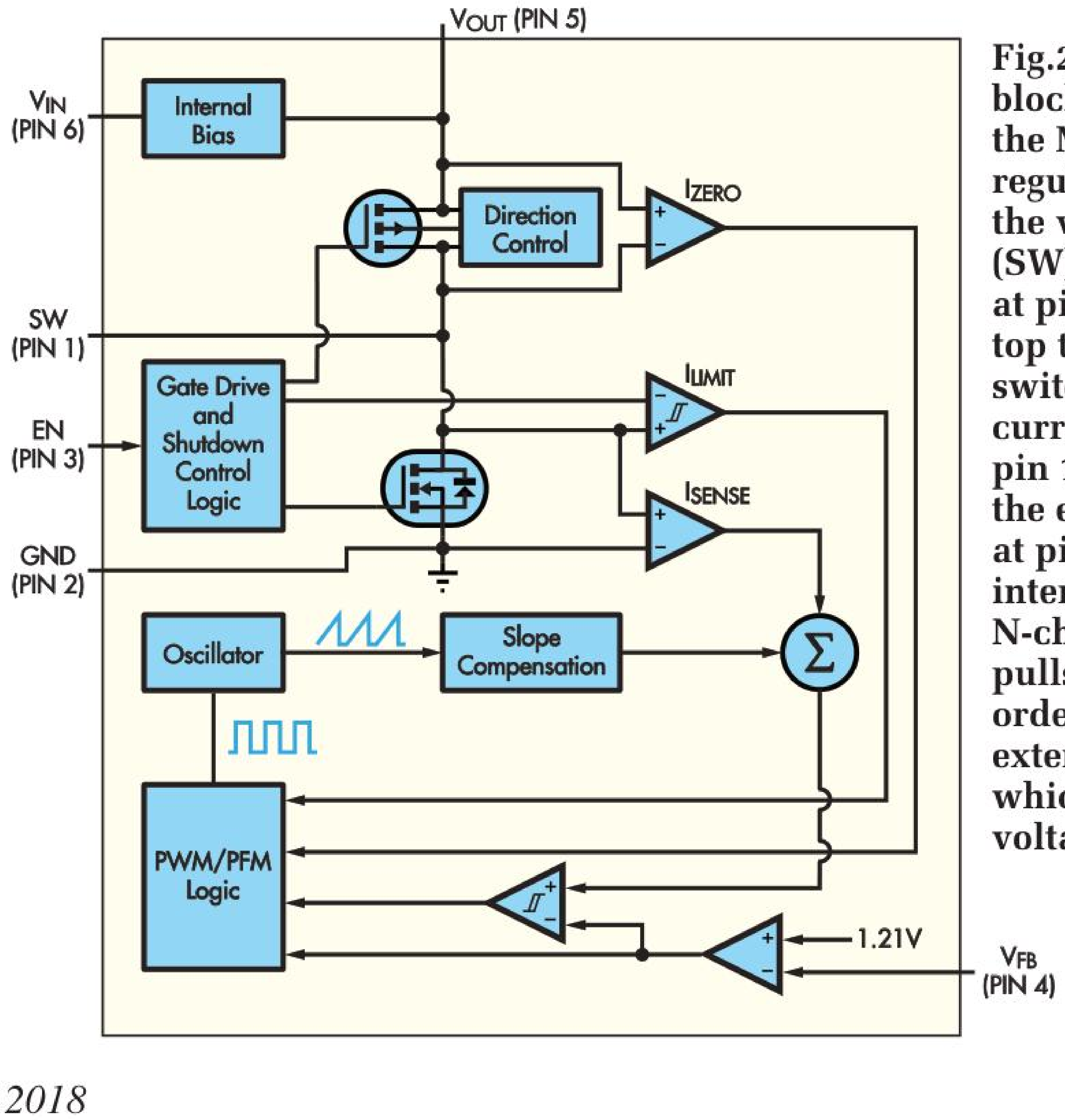


Fig.2: internal block diagram of the MCP1640 boost regulator (REG1). Once the voltage at pin 1 (SW) rises above that at pin 5 (V_{OUT}), the top transistor in REG1 switches on to allow current to flow from pin 1 to 5. This charges the external capacitor at pin 5. The other internal transistor (an N-channel MOSFET) pulls pin 1 low, in order to charge the external inductor which provides the voltage boost.

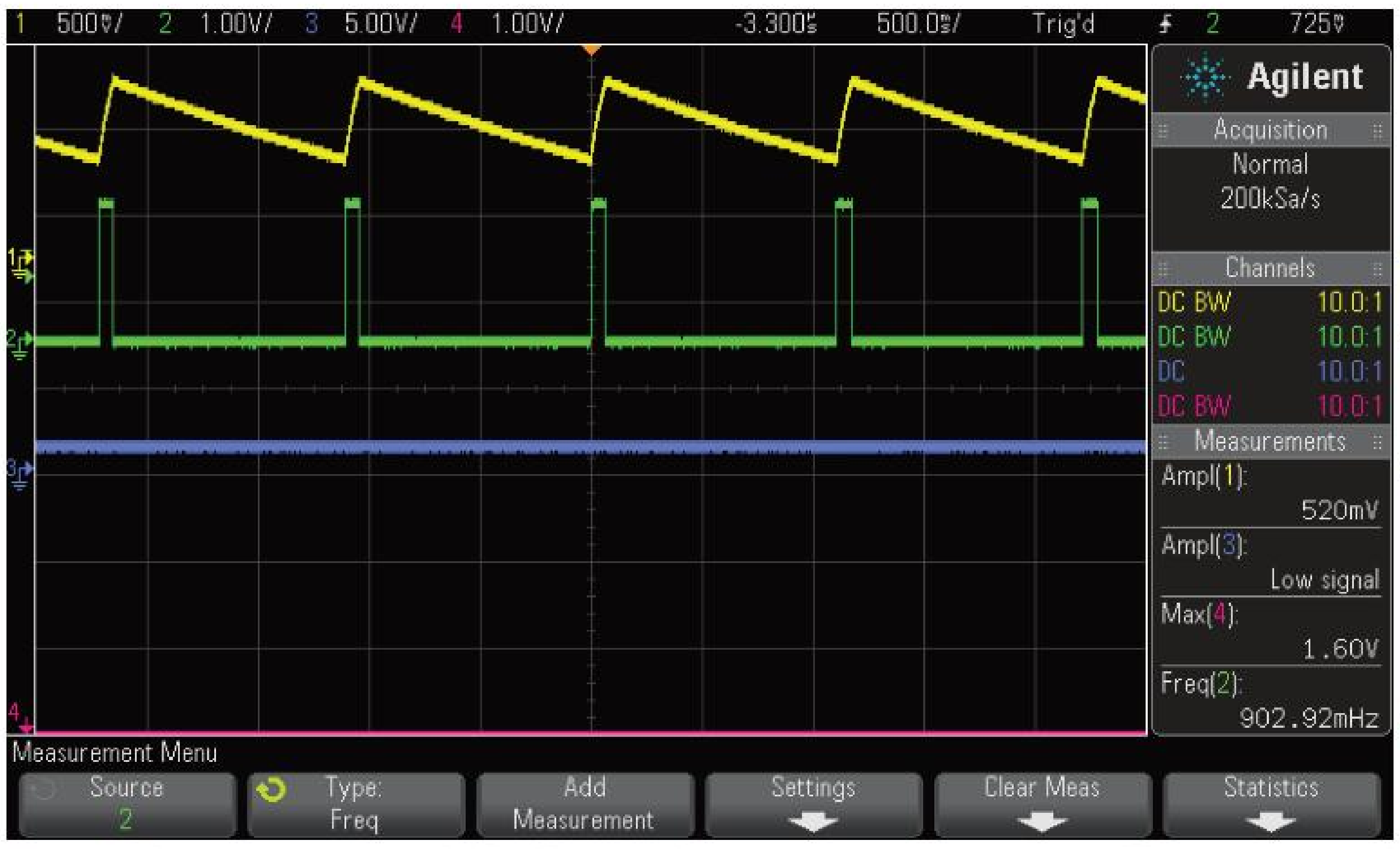

1 500mV/ 2 1.00V/ 3 5.00V/ 4 1.00V/ -3.300s 500.0ms/ Trig'd 2 725mV
Agilent
Acquisition
Normal
200kSa/s
Channels
DC BW 10.0:1
DC BW 10.0:1
DC 10.0:1
DC BW 10.0:1
Measurements
Ampl(1): 520mV
Ampl(3): Low signal
Max(4): 1.60V
Freq(2): 902.92mHz
Measurement Menu
Source 2
Type: Freq
Add Measurement
Settings
Clear Meas
Statistics

Fig.3: there is enough light on the LDR to attenuate the output of pin 4 to a low voltage; thus REG1 is not triggering. The yellow trace is pin 2 of IC1 while green is at pin 4.

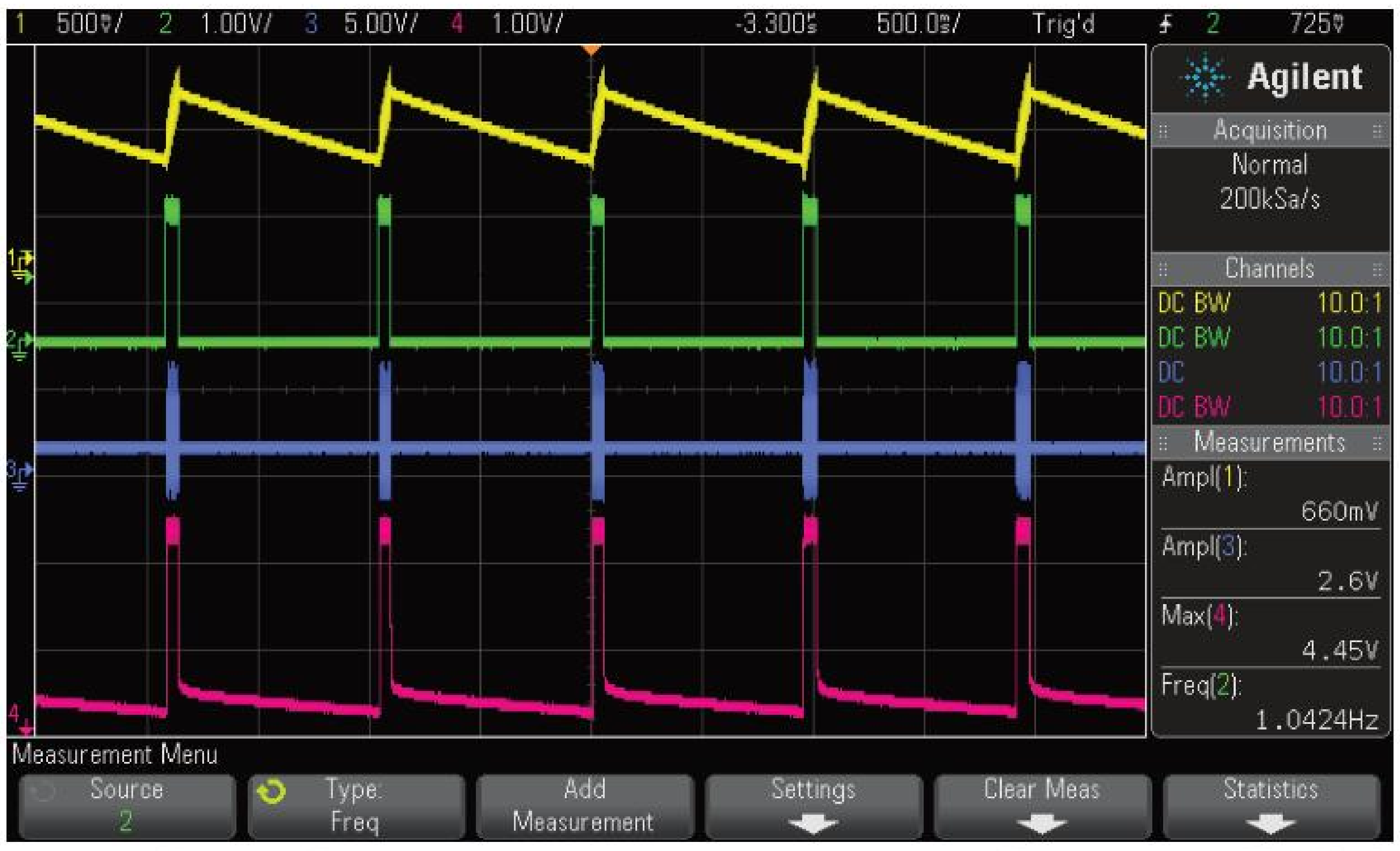

1 500mV/ 2 1.00V/ 3 5.00V/ 4 1.00V/ -3.300s 500.0ms/ Trig'd 2 725mV
Agilent
Acquisition
Normal
200kSa/s
Channels
DC BW 10.0:1
DC BW 10.0:1
DC 10.0:1
DC BW 10.0:1
Measurements
Ampl(1): 660mV
Ampl(3): 2.6V
Max(4): 4.45V
Freq(2): 1.0424Hz
Measurement Menu
Source 2
Type: Freq
Add Measurement
Settings
Clear Meas
Statistics

Fig.4: shows the same traces as Fig.3 except the LDR is shaded from light so that the enable pulses reach REG1. The blue trace is pin 1 of REG1, while pink is at LED1's anode.

Note that should the supply voltage be more than 1.21V above the forward voltage of LED1, the current flow will be higher than intended. However, R1 will still limit this current, albeit at a higher level.

But even with a very low forward voltage for LED1 at around 1.8V, you would need a supply of over 3.01V (1.8V + 1.21V) for this to happen and then the increase in current would be minor; no more than a few milliamps.

Because REG1's feedback is set up to regulate the current through LED1, the voltage supplied to LED1's anode pin will automatically be adjusted to take into account its forward operating voltage, which will depend on its colour.

For example, blue LEDs normally have a forward voltage of at least 3V, while red LEDs will often operate below 2V. REG1 will simply supply more voltage to a blue LED than a red one, in order to achieve the pre-set current flow.

However, were LED1 to become disconnected (eg, due to an intermittent section of wire, a bad solder joint or if it fails), because no current could flow through R1, the output voltage could increase to an unsafe level, possibly damaging REG1 or other components.

To avoid this, we've included zener diode ZD1. Should the output voltage exceed 6.81V (5.6V for ZD1 plus 1.21V at pin 4 of REG1), ZD1 will conduct and prevent REG1's output from rising any higher until the connection for LED1 is fixed.

Operating waveforms

The scope grabs of Figs.3-6 show the operation of the flasher running from a single AAA cell.

In each case, the yellow trace shows the voltage at pin 2 of IC1, depicting the charging and discharging of timing capacitor C1. The green trace shows the voltage at pin 4 of IC1, the pulses which enable REG1 when the LDR is in darkness and also determine the length of the LED flash. The blue trace shows the voltage at pin 1 of REG1, the switch terminal, while the pink trace shows the voltage at the anode of LED1.

In Fig.3, there is enough light on the LDR to attenuate the output of pin 4 to a low voltage and thus REG1 is not being triggered. You can see the charge/discharge sawtooth ramp of the timing capacitor at top and the resulting trigger pulses below.

The frequency read-out is 900mHz, ie, just a little less than 1Hz (with a 1µF timing capacitor). The amplitude of the sawtooth waveform can be seen to be 520mV, around a third of the 1.5V supply voltage.

Fig.4 shows the exact same traces, but this time the LDR is shaded so that the enable pulses reach REG1. You can see that the frequency has increased slightly, to 1.04Hz, due to the slight drop in cell voltage from the extra current drain and also, to some extent, due to the noise from REG1 affecting the operation of IC1.

You can also now see some evidence of the switching output of the boost operator in the blue trace (although note that, due to the high frequency, the scope is underestimating its amplitude) and the 4.45V now being applied to the LED anode in ~60ms bursts.

Fig.5 is similar to Fig.4, but with a shorter timebase so you can better see the operation of REG1 in detail. The switching frequency is 485kHz and you can see how pin 1 of REG1 is pulled to 0V briefly, after which it shoots up to over 4V, before dropping down to 0V as the energy in L1 is exhausted. It then sits at around 1.5V (ie, the supply voltage) while D1 is reverse-biased before being pulled low again for the next cycle.

Fig.6 shows the measured current from the AAA cell while there was sufficient light on the LDR to prevent the LED from flashing. We connected a 1:1 scope probe across a 100Ω shunt resistor placed in series with

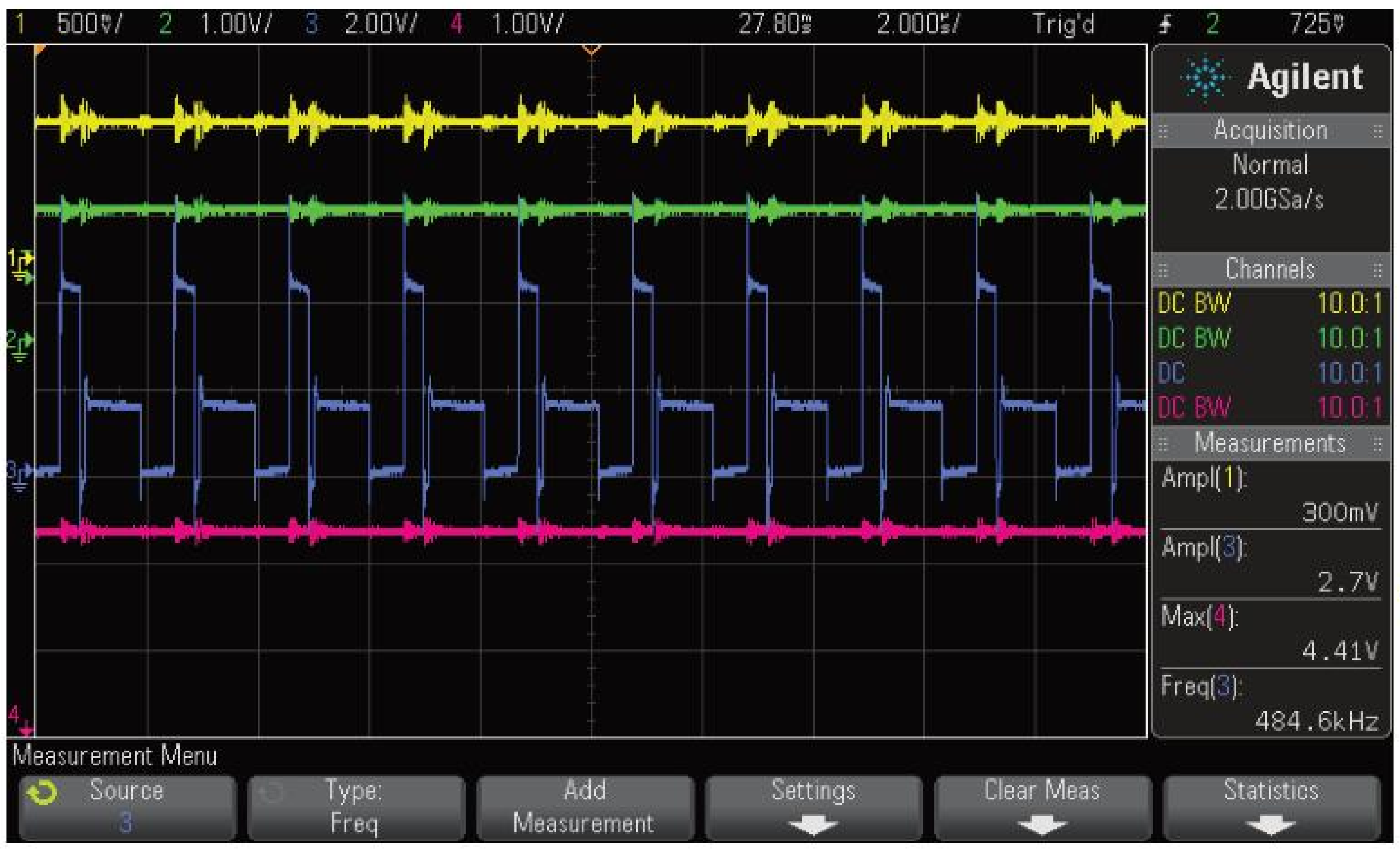

1 500mV/ 2 1.00V/ 3 2.00V/ 4 1.00V/ 27.80s 2.000µs/ Trig'd 2 725mV
Agilent
Acquisition
Normal
2.00GSa/s
Channels
DC BW 10.0:1
DC BW 10.0:1
DC 10.0:1
DC BW 10.0:1
Measurements
Ampl(1): 300mV
Ampl(3): 2.7V
Max(4): 4.41V
Freq(3): 484.6kHz
Measurement Menu
Source 3
Type: Freq
Add Measurement
Settings
Clear Meas
Statistics

Fig.5: is the same as Fig.4 except over a shorter timebase, letting you easily see the switching of REG1 (blue) in detail, which has a switching frequency of 485kHz in this case.

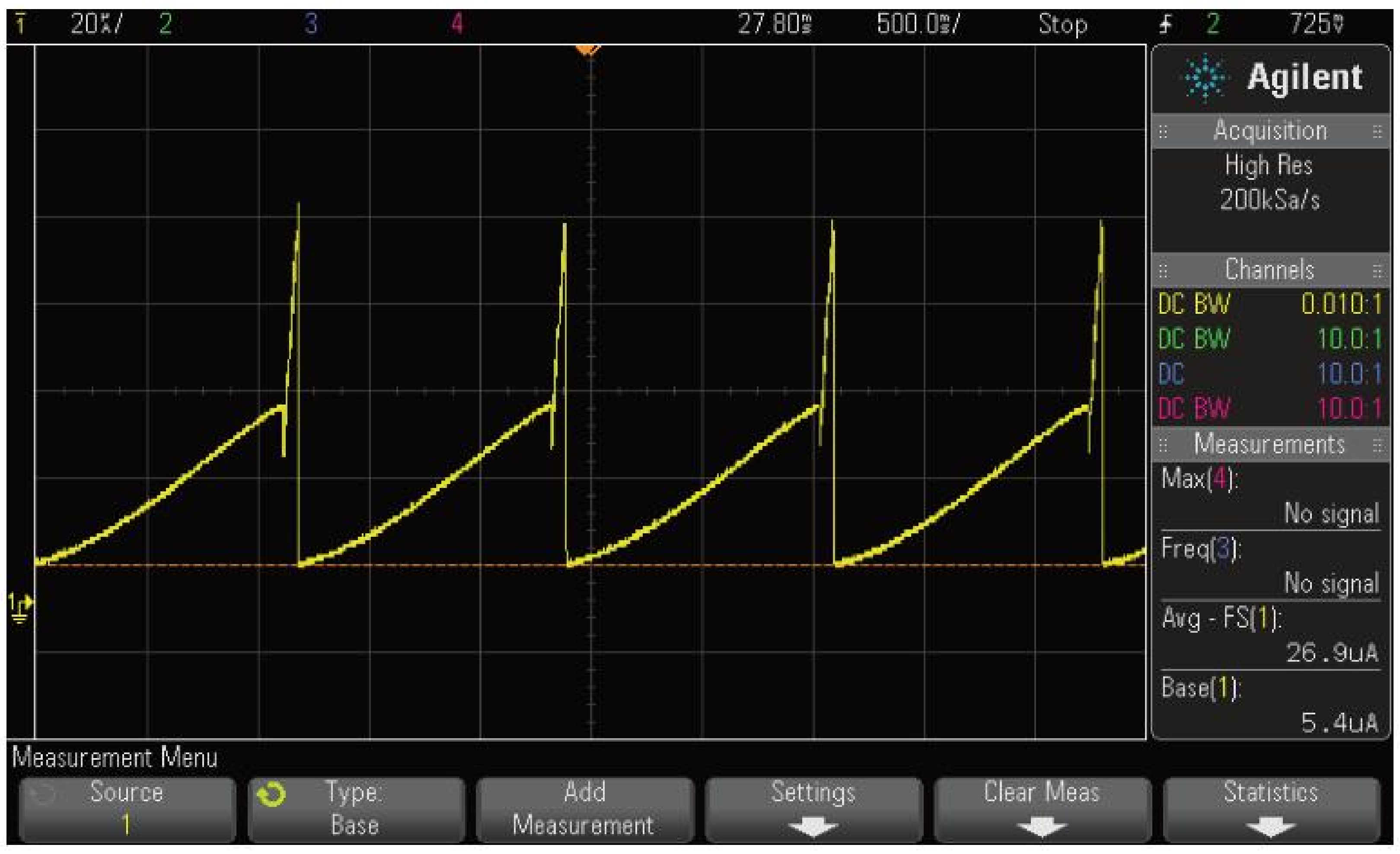
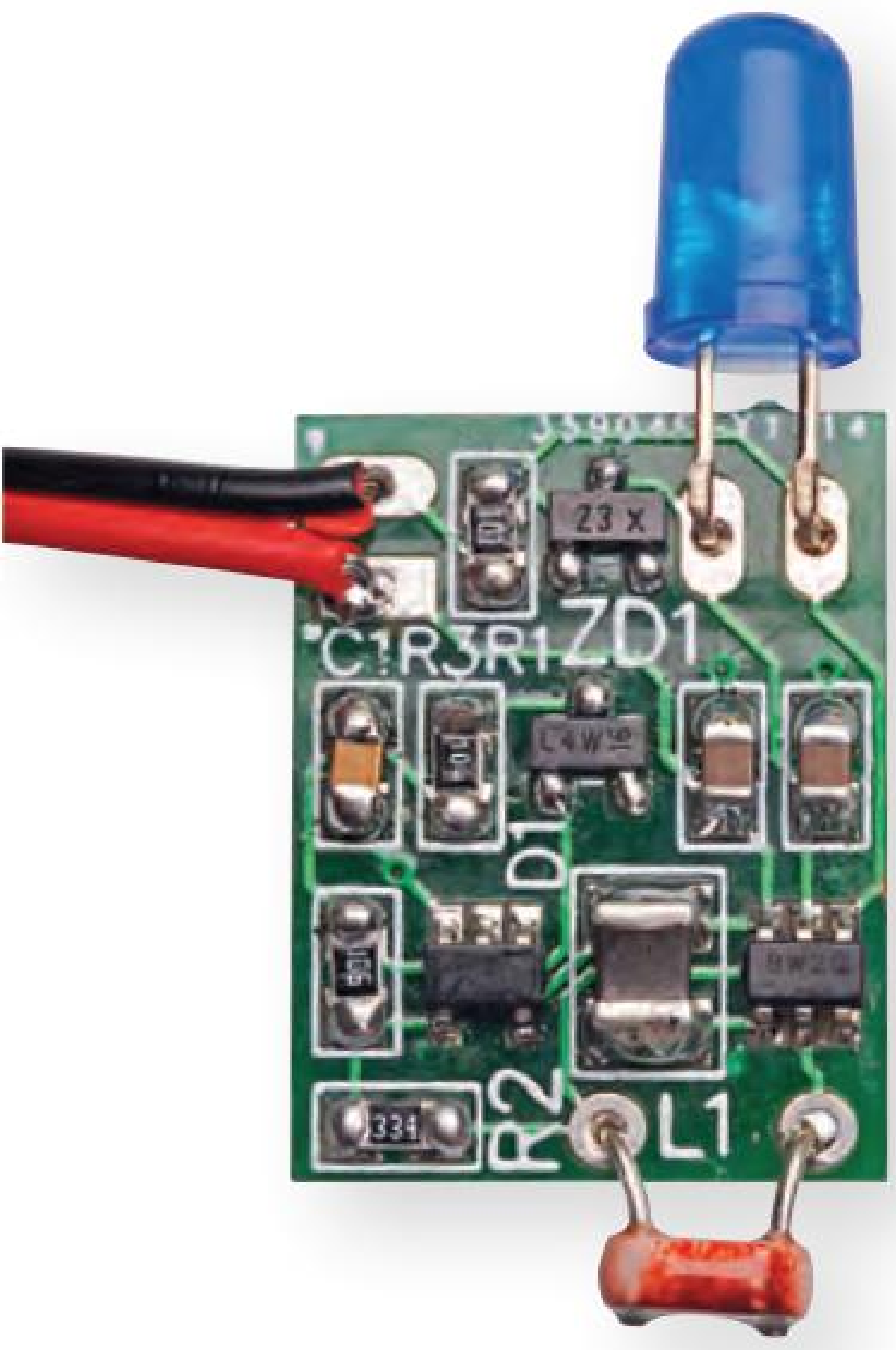
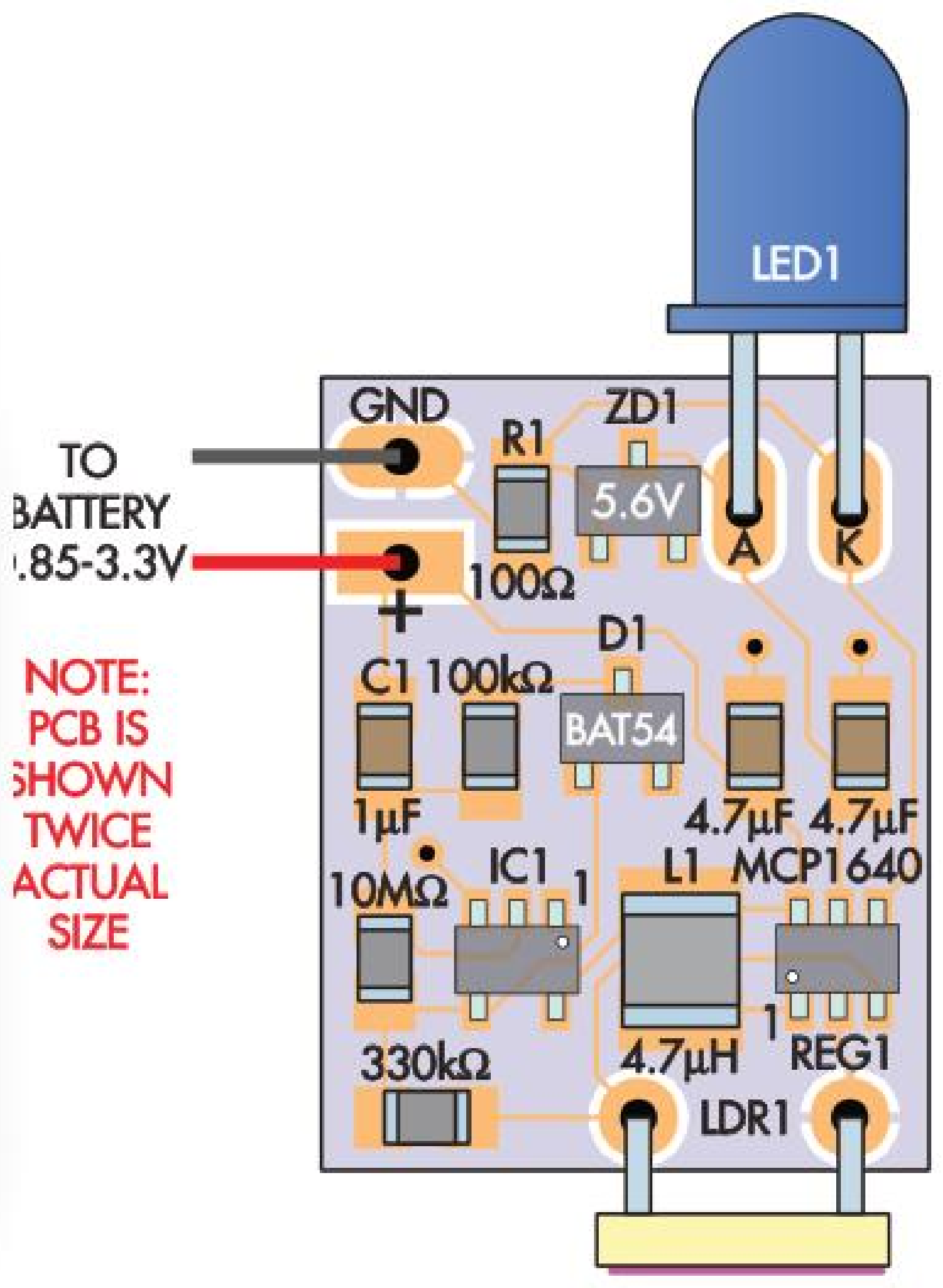
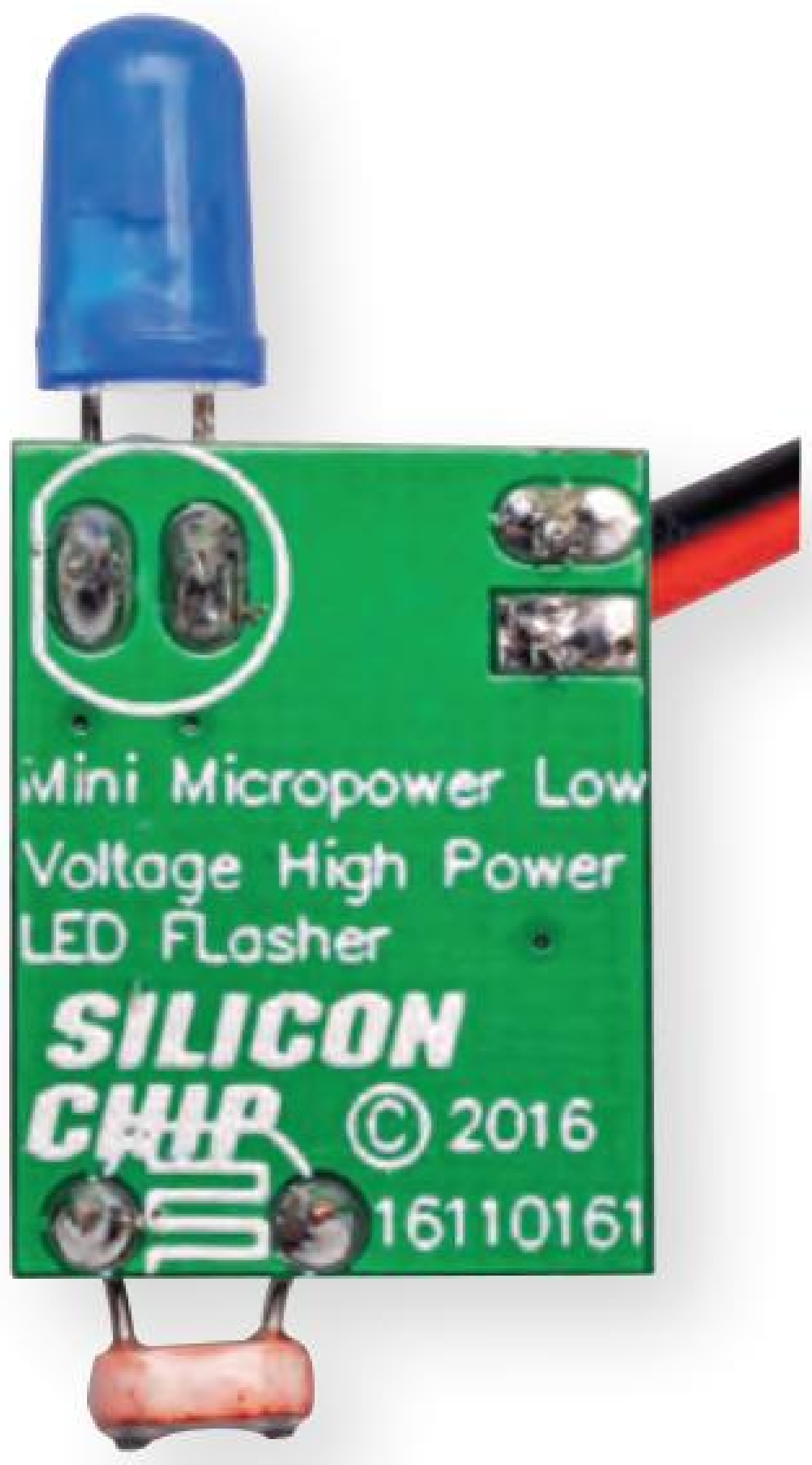

1 20µ/ 2 3 4 27.80s 500.0ms/ Stop 2 725mV
Agilent
Acquisition
High Res
200kSa/s
Channels
DC BW 0.010:1
DC BW 10.0:1
DC 10.0:1
DC BW 10.0:1
Measurements
Max(4): No signal
Freq(3): No signal
Avg - FS(1): 26.9uA
Base(1): 5.4uA
Measurement Menu
Source 1
Type: Base
Add Measurement
Settings
Clear Meas
Statistics

Fig.6: shows the measured current draw from one AAA cell while there was enough light on the LDR to prevent the LED from flashing.



When building the *Flasher*, it's best to use an X5R (±20%) or X7R (±10%) capacitor for C1, as its value won't drift as much with temperature.





LDR1, which is optional, can either be soldered to the board as shown at the bottom of the PCB, or attached via flying leads.

Fig.7: (centre) overlay diagram for the *LED Flasher*, which is built on a 15 × 19mm PCB. This makes it easy to fit in a model train or toy car.

the cell and set the scope to measure in microamps.

We then used its measurement facility to average the result. Note that there's a significant DC offset of 5.4µA in the measurement, which you have to subtract to get an accurate reading. Note also how the current draw changes during the oscillator cycle and spikes when the oscillator output is briefly high.

Component value selection

Using the values shown will give a flash rate of around 1Hz at 1.5V and a peak LED current of around 12mA. If you want a slower flash rate, simply increase the value of C1, eg, 2.2µF will result in around 2.2s between flashes (0.45Hz); 470nF will give around 0.5s between flashes (2Hz), etc. If you need a rate that's between those that are easy to achieve with preferred values, you can quite easily parallel two SMD ceramic capacitors by soldering one on top of the other.

It's best to use X5R (±20%) or X7R (±10%) capacitors for C1 to avoid too much variation with temperature, but remember that regardless of the accuracy of C1, it will vary somewhat with supply voltage and you may need to experiment with capacitance if you want a particular rate.

Setting the peak LED current is easy; simply select R1 = 1.21V ÷ (current in amps). So for example, if you want to set it at 5mA (which will still be quite bright), use 1.21 ÷ 0.005 = 242Ω or the nearest value, in this case, 240Ω.

Keep in mind that the current drawn from the supply is substantially higher than this programmed current due to the fact that the supply voltage is normally considerably lower than that required to drive the LED, and due to limited efficiency.

For example, on our prototype we measured a peak draw of around 50mA from the 1.5V (nominal) cell when LED1 was receiving 12mA, with its anode at around 4.6V. Of course, the battery only has to supply this 50mA for the 8% or so of the time that LED1 is lit.

The average battery drain can be reduced by lowering the duty cycle. To do this, reduce the value of R2, to as low as 15kΩ, which should give a duty cycle of around 1%. Likewise, the value of R2 can be increased, up to about 2.2MΩ, for a duty cycle of up to around 25%.

Power supply

You can use one or two AA or AAA cells, a 3V Lithium button cell or a 3.3V regulated supply. Keep in mind that the relatively high internal resistance of a button cells places an upper limit on how much current the circuit can reasonably draw, so we recommend increasing the value of R1 and possibly lowering the value of R2 for reasonable performance and battery life if using a button cell.

Construction

The *LED Flasher* is built on a tiny double-sided PCB measuring just 15 × 19mm. That makes it easy to fit inside something like a model railway carriage or toy car, especially since it can be run from a single AAA cell.

The PCB is coded 16110161 and carries 12 SMD components plus the LED, optional LDR and power supply header/wires. The overlay diagram, shown twice actual size, is shown in Fig.7.

None of the components are overly difficult to solder but IC1 and REG1 have the closest pin spacings. Start with REG1.

This has six pins, three on each side, so you will have to examine it with a

Parts list

Ultra-low-voltage Mini LED Flasher

1 double-sided PCB, available from the *EPE PCB Service*, coded 16110161, 15 × 19mm
1 4.7µH 100mA+ inductor, size 3226/3216 (imperial 1210/1206) (eg, Taiyo Yuden CBC3225T4R7MR or BRL3225T4R7M)
1 LDR, dark resistance >1MΩ (eg, GL5528) (optional)
1 2-way pin header with plug or light duty twin lead
1 1.2-3.3V (nominal) battery or DC power supply

Semiconductors
1 SN74AUP1G14DBVR schmitt trigger inverter, SOT-23-5 (IC1)
1 MCP1640T-I/CHY* synchronous boost regulator, SOT-23-6 (REG1)
1 high-brightness LED, size and colour to suit application; 3mm and 5mm through-hole types are suitable (LED1)
1 5.6V SMD zener diode, SOT-23 (ZD1)
1 BAT54 SMD schottky diode, SOT-23 (D1)

Capacitors
2 4.7µF 10V X5R SMD size 2012/1608 (imperial 0805/0603)
1 1µF** 6.3V X5R/X7R SMD size 2012/1608 (imperial 0805/0603) (C1)

Resistors (all 1% 1/4W SMD size 2012 or 1608 [imperial 0805/0603])

1 10MΩ	1 330kΩ	1 100kΩ#	1 100Ω

* **do not** use MCP1640B, MCP1640C or MCP1640D
** increase value for lower flash rate or reduce for faster rate
# increase value for longer flash period or reduce for shorter period

magnifying glass under good light to find the printed dot which indicates its pin 1. Orient REG1 so that pin 1 is closest to L1; ie, on the side nearest to the LDR mounting pads.

Melt a small amount of solder on one of the pads for REG1, then carefully slide it into place while heating the solder on that pad. Check its orientation with a magnifier and if necessary, re-melt that solder and gently nudge the component until all six leads are positioned properly above their pads.

Now solder the pins on the opposite side of the one you tack-soldered, then go back and solder the three on the other side (refresh the solder on that initial pin).

The solder will flow more easily if you spread a little flux paste over the pins of the IC. Since they are so close together, when you solder them, there is a high chance that the solder will bridge the pins.

This can be cleaned up by adding a little flux paste and then applying some solder wick and a hot soldering iron. It should suck the excess solder right off the pins once it reaches the right temperature. You can then slide the solder wick away from the part and remove the soldering iron.

Clean off with methylated spirits, isopropyl alcohol or flux cleaner and then check carefully with a magnifier that all the joints are good and there are no bridges. You can then move on to soldering IC1 using a similar technique. Its orientation should be obvious since it has two pins on one side and three on the other. You will find soldering the side with the two pins easier due to the increased spacing.

With that in place, soldering the remaining SMDs should be quite easy. Don't get ZD1 and D1 mixed up as the packages look very similar. It will take a little more time to form the solder joints for L1 than the resistors and capacitors due to its larger size, but the passive components can all be soldered using a similar technique as for the semiconductors.

LED1 can either be mounted on the board or via flying leads, depending on what's more convenient. Just make sure to get the anode and cathode the right way around. It can be a 3mm or 5mm LED or even a 2012/0805 SMD LED soldered directly across the pads, if that suits you.

LDR1 can also be soldered to the board or attached via flying leads. It's located at the opposite end of the board from LED1 to prevent optical feedback from causing LED1 to flicker; however, you can probably get away with mounting them in reasonable proximity if necessary, as long as they don't face each other. As mentioned earlier, if you don't want the *Flasher* disabled by a high ambient light level, simply leave LDR1 off.

There is no reversed-supply protection on this board (to minimise size and voltage loss) so be very careful in wiring up the supply connections. Make sure to connect the negative end of your power supply to the corner pad (GND) of CON1 and it should be OK.

A power switch can be wired in series with either supply wire should that be necessary, using either a two-pin vertical or horizontal header or, as with our prototype, simply solder a pair of flying leads to these pads. Make sure they can't move around too much, though, or the wires will eventually break due to metal fatigue.

That's it. Once you've applied power and LDR1 (if fitted) is in the dark, LED1 should start flashing after C1 has charged up to its normal voltage, which may take a few seconds.

Reproduced by arrangement
with SILICON CHIP
magazine 2018.
www.siliconchip.com.au

Laser Why tolerate when you can automate?

X-10 Home Automation

KATS AV transmission and IR control system

Barix Ethernet based MP3, communications and control systems

www.laser.com

Integrators, Installers, Trade and Retail customers welcome

C-Bus Shop
C-Bus and
C-Bus Wireless

www.cbus-shop.com

Laser Business Systems Ltd
Tel: +44 (0) 20 8441 9788
Fax: +44 (0) 20 8449 0430
Email: info@laser.com
16 Garthland Drive, EN5 3BB

PoLabs

For more information or software download please visit

www.poscope.com/epe

PoKeys
Connect, Control

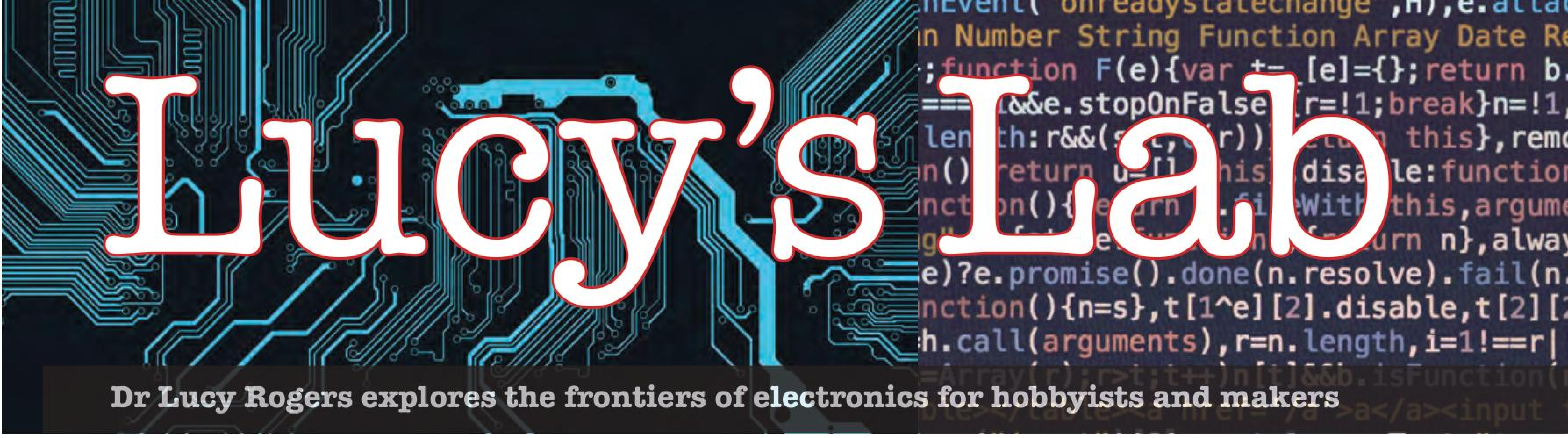
- USB
- Ethernet
- Web server
- Modbus
- CNC (Mach3/4)
- IO
- PWM
- Encoders
- LCD
- Analog inputs
- Compact PLC

Stepper motor drivers
Drive

- up to 256 microsteps
- 50 V / 6 A
- USB configuration
- Isolated
- up to 32 microsteps
- 30 V / 2.5 A

PoScope Mega1+
PoScope Mega50
Measure

- up to 50MS/s
- resolution up to 12bit
- Lowest power consumption
- Smallest and lightest
- 7 in 1: Oscilloscope, FFT, X/Y, Recorder, Logic Analyzer, Protocol decoder, Signal generator



Lucy's Lab

Dr Lucy Rogers explores the frontiers of electronics for hobbyists and makers

Gather round the Wi-Fi

I did a radio interview recently, and an (older) friend asked what time I was on the 'wireless', which got me thinking about wireless things.

It was back in 1894 that Marconi started playing with radio waves to develop a wireless telegraph system. In the early 1900s, the 'wireless' was the most modern form of communication, and people would 'gather round the wireless' to hear the latest news or be entertained.

Nowadays, the term 'wireless' is quaint (or ironic), and will probably result in a few funny looks from the younger generations. Nevertheless, today we use wireless technology all the time – so much so, we hardly think about it. The only time I ever really give a thought to Wi-Fi is when I need the password. And if I am without it for long enough, I start to twitch. Other than that, it's just the magic that makes me connected to the world. I do remember – with a shudder – having to plug the phone line into my computer to get on the Internet; and having to get off the Internet because someone wanted to make a phone call. But what is Wi-Fi and how does it work? This is one of those 'Explain why $V = IR$' questions. I *thought* I knew, until I started trying to put it in to words.

Nonsense name

So, because I like to understand as soon as I realise what I don't know, I started investigating. First, what does 'Wi-Fi' actually stand for? Well, it turns out, it doesn't stand for anything. It's not an acronym, nor the initials of its inventors, but a meaningless soundbite. The term 'Wi-Fi' was invented by a company called 'Interbrand' as a catchier name for 'IEEE 802.11b Direct Sequence' – and maybe they did have a point. Interbrand also created the names 'Compaq' and 'Prozac', but for different clients. 'Wi-Fi' was the name selected by the founders of the Wireless Ethernet Compatibility Alliance because it rhymed with 'Hi-Fi'. But the marketing people got upset and decided it should 'stand' for something – and they called it 'wireless fidelity', which is equally meaningless. Wireless Fidelity? Faithfulness without strings? – yes, complete nonsense.

Ultimately, the term 'Wi-Fi' is really just letting you know that something is IEEE 802.11 compliant. This is the set of rules for sending data wirelessly.

As we know, data is just a string of ones and zeros – known as 'binary'. If I wanted to send the message 'Lucy is amazing' in binary then a) My head wouldn't fit through the door and b) the word 'Lucy' alone is 32 digits (four binary numbers, each with eight binary digits – 'bits') and sending all those ones and zeroes would take, in data terms, quite a long time – even though, to me, it feels that data transfer is instantaneous.

The computer scientist and US Navy rear admiral, Grace Hopper, used to carry around an 11.8-inch (30cm) long piece of wire – because that's how far light travels in a nanosecond. She used it because she had trouble visualising a billion, and therefore a billionth, and so when it came to a billionth of a second – a nanosecond – she had no idea. And she realised if she had no idea, then colleagues, children and, more importantly, admirals, probably could do with some visual help. Especially when they asked why talking via a satellite takes so long. Or if they thought that data transfer was instantaneous. Incidentally, a microsecond is represented by 984 feet (300m) of cable.

However, data does not have to be sent one chunk at a time, thanks to the development of methods to break up the message. Imagine how annoying it would be to have the postal service deliver you *EPE* one page at a time. To make this faster, each letter containing each page could be bundled up with others and sent in the same post van. But what if there were too many letters for one van? Just get another van? But what if that van gets lost?

Well this is why we rely on the Wi-Fi 'standard'. This tells us how the pages should be split up at the start and re-assembled at the end, how to ask for pages to be re-sent if they get lost and how to tell the postman the address to send them to and even how each page is put in the envelope and how much licking you need to affix the stamp.

Remarkable actress

This is (roughly) what the actress Hedy Lamarr invented with the composer George Antheil. At the beginning of World War II, they developed a radio guidance system for Allied torpedoes, which used spread spectrum and frequency hopping technology. And it's this ground-breaking work on efficient data transfer that underlies Wi-Fi.

My unconscious bias has been knocked again – as this didn't really strike me as a thing that an actress (or a composer) would do. (You can read more about her extraordinary life at: **https://en.wikipedia.org/wiki/Hedy_Lamarr**). It turns out Hedy was mainly self-taught, and invented things in her spare time. She also improved traffic lights and invented a tablet that made a drink fizzy. Although this last idea was unsuccessful commercially, as the resulting drink tasted like Alka-Seltzer. George was also pretty extraordinary. Hedy came up with the idea of making radio frequency signals jump rapidly and randomly from frequency to frequency so that they couldn't be tracked – and so, for radio-controlled torpedoes, they couldn't be jammed. But at that time there was no way to operate this frequency-hopping system. However, George realised that you could do it by using miniaturised self-playing piano mechanisms. The Navy didn't use the system at the time though, but with the invention of the transistor and other small electronic components, their system was finally applied to all military communications, then to GPS, then to car telephones and finally Bluetooth and Wi-Fi.

So Wi-Fi really isn't magic – it was built on inventions made by a few amazing humans, it follows some rules, and it was given a made-up name. But it is still 'magical'.

The AD9850 DDS Module

In the April issue, we covered the AD9833 Direct Digital Synthesiser (DDS) chip. This time, we're looking at modules based on its big brother, the AD9850. Typically combined with a 125MHz crystal oscillator, it can be programmed to produce sinewaves to beyond 40MHz, possibly accompanied by a square or pulse waveform. It is again controlled via an SPI serial interface.

Using Cheap Asian Electronic Modules Part 9: by Jim Rowe

We won't explain how a DDS chip works again, as we covered that quite thoroughly in the article mentioned above, in the April 2018 issue. There are a couple of modules using the AD9850 chip in conjunction with a 125MHz oscillator, with the one shown in the photos probably the most common. The other module is very similar in most respects, apart from having a different PCB layout.

In the module shown, the fact that the AD9850 is coupled with a 125MHz crystal oscillator means that it can be programmed to produce any output frequency from 0.0291Hz to over 62MHz in 0.0291Hz increments (more about the practical frequency limits later). This means it has a frequency range about five times that of the AD9833, with a resolution about 3.4 times finer (0.0291Hz compared with 0.1Hz).

Although the AD9850 doesn't provide the same choice of output waveforms as the AD9833, it does offer the basic sinusoidal waveform, plus a derived rectangular waveform with bipolar outputs and an adjustable duty cycle. This allows it to produce anything from narrow positive pulses through to a square wave to narrow negative pulses.

The AD9850 chip itself is a little larger than the very tiny AD9833, but is still quite small. It comes in a 28-pin SSOP package, operates from either 3.3V or 5V and is described as low power – dissipating just 380mW when running with a 125MHz master clock from 5V, or only 155mW when operating from a 3.3V supply with a 110MHz master clock.

The AD9850-based module shown in the photos, which measures only 44.5 × 26mm and includes a 125MHz crystal oscillator, is currently being offered on eBay and AliExpress for prices ranging from £10 to £15, in many cases with postage included.

Inside the AD9850

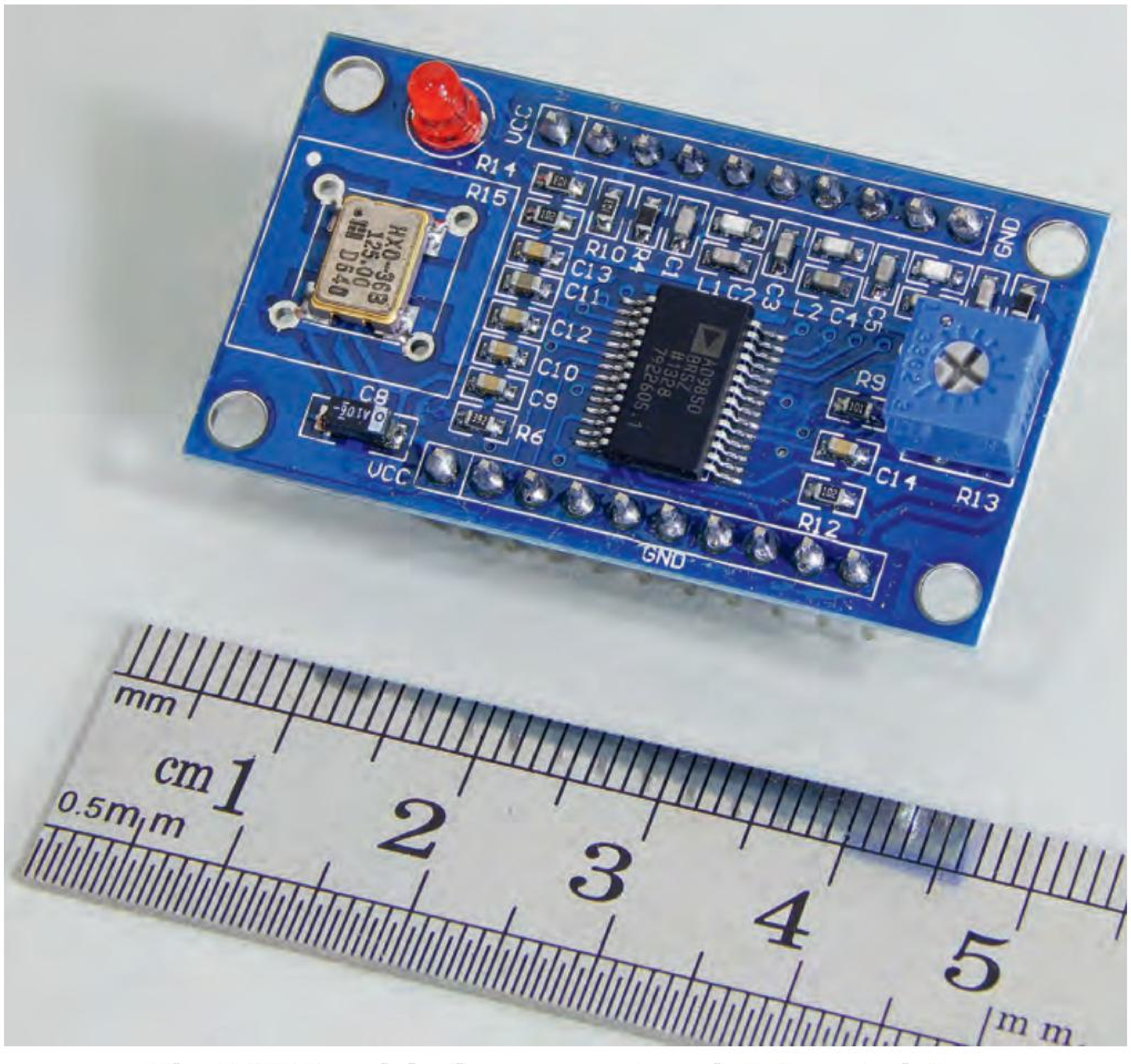
The block diagram of Fig.1 shows what's inside that compact 28-pin SSOP package. The main sections involved in basic DDS operation are those shown with a pale yellow fill. The high speed comparator at lower right is used for deriving the rectangular/square output waveform, as we'll see shortly.

Down at lower left is the 40-bit input register where data and instructions are loaded into the chip from almost any micro. With the AD9850, this can be done in two ways; in serial fashion via an SPI (Serial Peripheral Interface) bus like the AD9833, or by parallel loading via an 8-bit data bus.

Since the AD9850 needs a 40-bit word rather than two 14-bit words, this means that programming it gets a little more complicated than the AD9833.

With serial loading via the SPI bus, all 40 bits must be sent in sequence, while with parallel loading they must be sent as a sequence of five bytes (8-bit words). In both cases, they must be sent to the chip in a particular order (LSB first) and with the 32-bit frequency word sent before the 8-bit control/phase word.

Returning to Fig.1, just above the input register is the frequency/phase data register, also of 40 bits. This stores the data used to program the DDS in



The AD9850 module ahown approximately twice actual size.

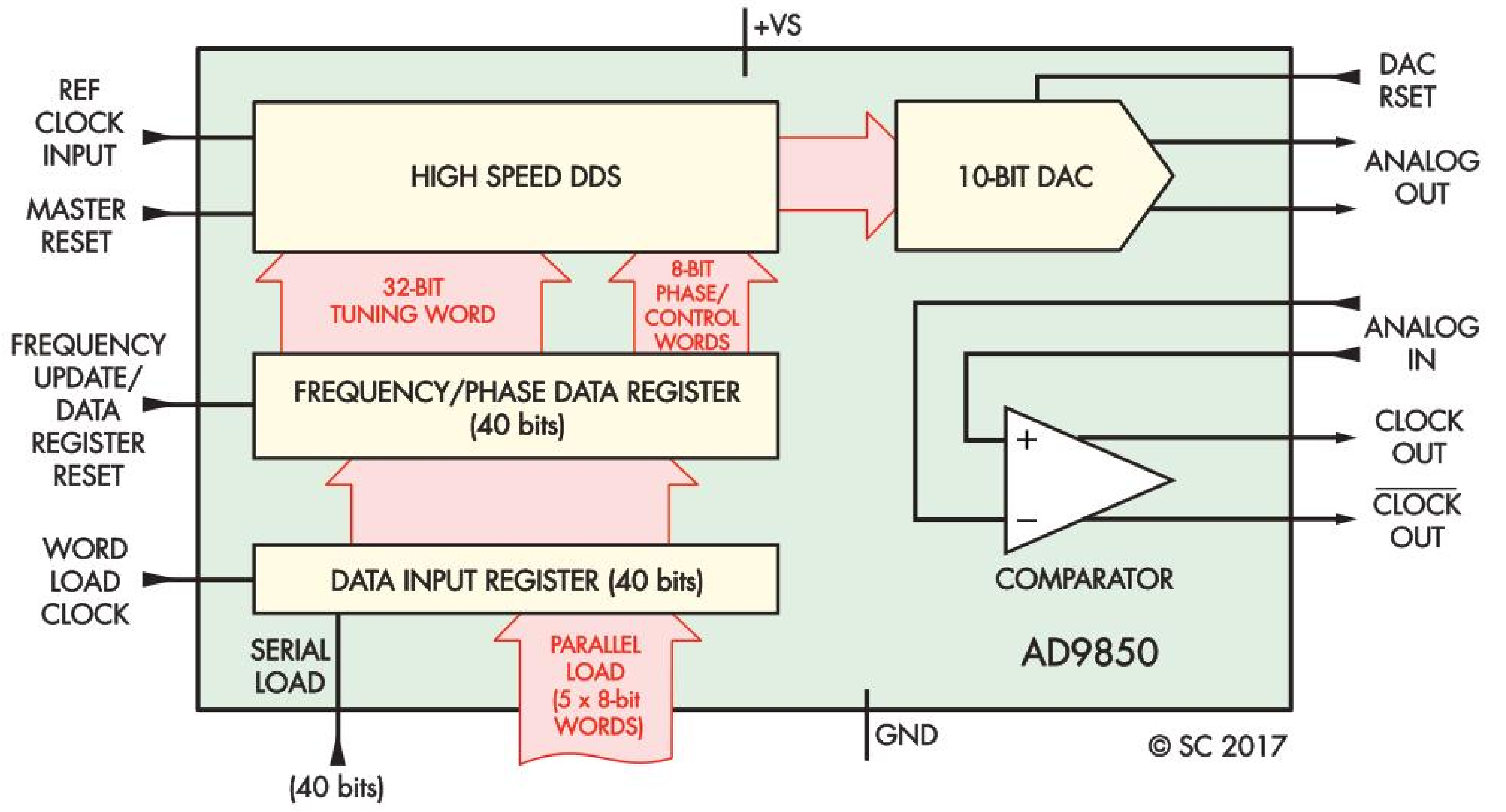
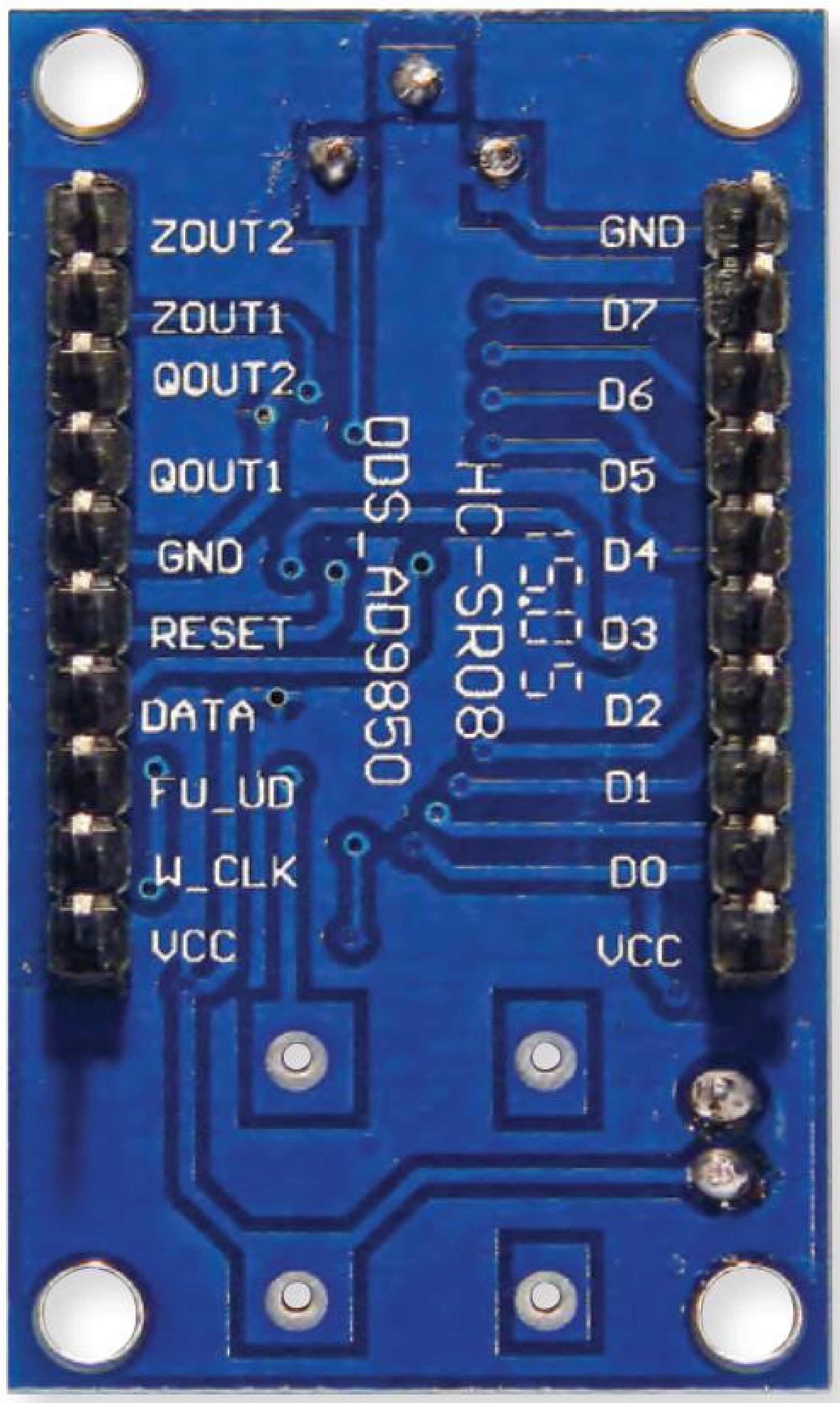

+VS
REF CLOCK INPUT
MASTER RESET
FREQUENCY UPDATE/ DATA REGISTER RESET
WORD LOAD CLOCK
HIGH SPEED DDS
10-BIT DAC
DAC RSET
ANALOG OUT
32-BIT TUNING WORD
8-BIT PHASE/ CONTROL WORDS
FREQUENCY/PHASE DATA REGISTER (40 bits)
ANALOG IN
CLOCK OUT
CLOCK OUT
COMPARATOR
DATA INPUT REGISTER (40 bits)
SERIAL LOAD
PARALLEL LOAD (5 x 8-bit WORDS)
AD9850
GND
© SC 2017
(40 bits)

Fig.1: internal block diagram of the AD9850 IC. This is somewhat simpler than the AD9833 featured previously as it has no facility to generate a triangle wave nor a square wave. However, the internal high-speed comparator at lower right can be used to generate a fixed or variable-duty-cycle square wave derived from the sinewave output and a DC reference voltage.


ZOUT2
ZOUT1
QOUT2
QOUT1
GND
RESET
DATA
FU_UD
W_CLK
VCC
GND
D7
D6
D5
D4
D3
D2
D1
D0
VCC
DDS_AD9850
HC-SR08

This photo of the underside of the AD9850 DDS module shows the pin header connections that can be used with a Micromite or Arduino.

terms of output frequency and phase modulation (if any).

Once the data has been loaded into the input register either serially or as five bytes, it is transferred into the frequency/phase register with a single positive-going pulse to the Frequency Update (FQ_UD) pin.

The high speed DDS 'heart' of the AD9850 is shown at upper left in Fig.1, with its 125MHz master clock input labelled 'Ref Clock Input'. Then to the right of the DDS block is the very fast 10-bit DAC (digital-to-analogue converter), used to provide the AD9850's main sinewave output. Note that the use of a 10-bit DAC gives the device a sinewave amplitude resolution of 1024 levels.

The complete module

Now it's time to turn your attention to Fig.2, which shows the complete circuit for the 44.5 × 26mm module shown in the photos. It has quite a few components, comprising the AD9850 DDS chip (IC1) and its equally small (6.5 × 4.5mm) 125MHz crystal oscillator, a red power LED, seven SMD resistors, 14 SMD capacitors, three SMD inductors and a small trimpot.

10-way SIL connectors CON1 and CON2 provide all the signal and power connections to the module. Most of

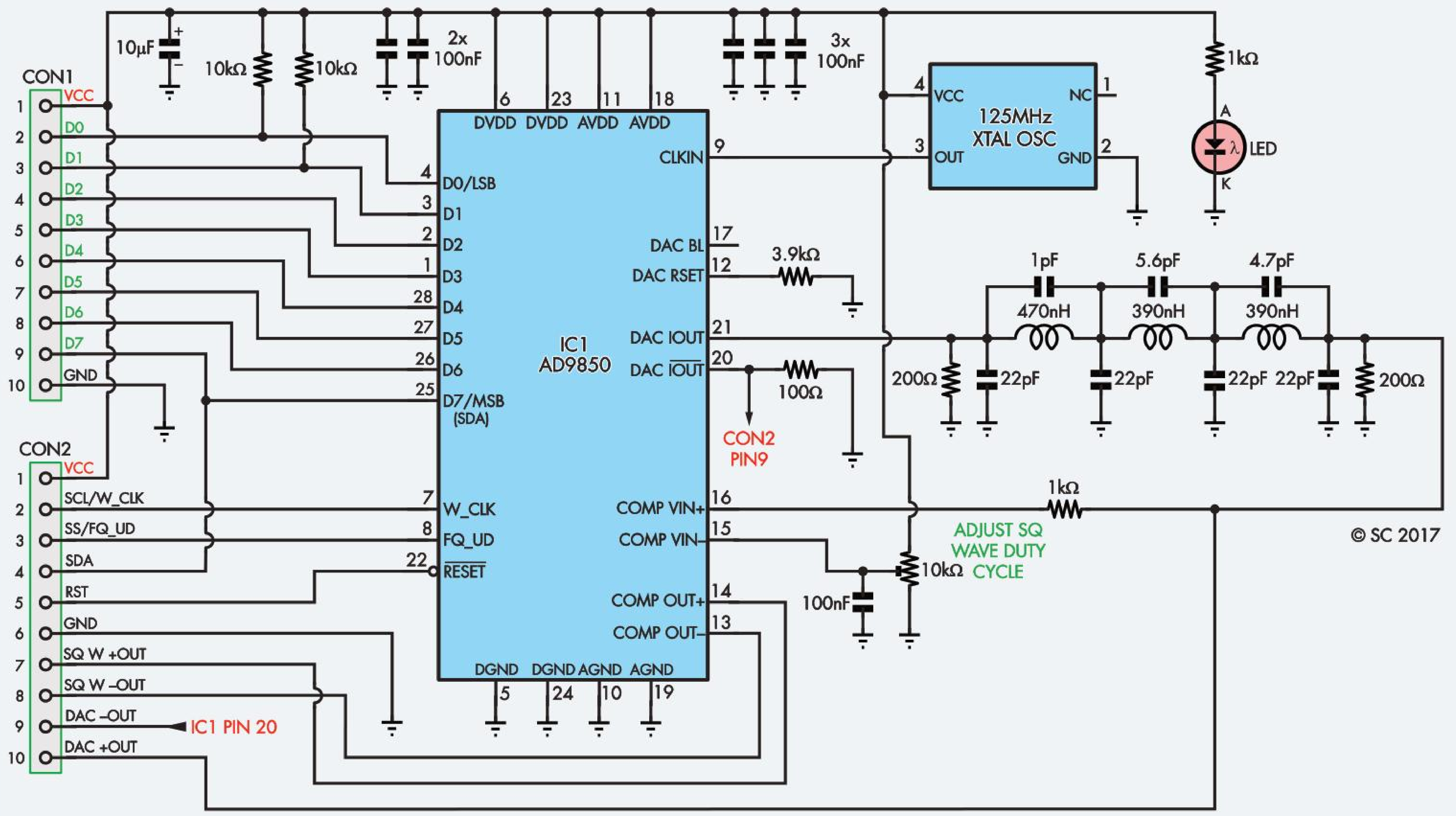
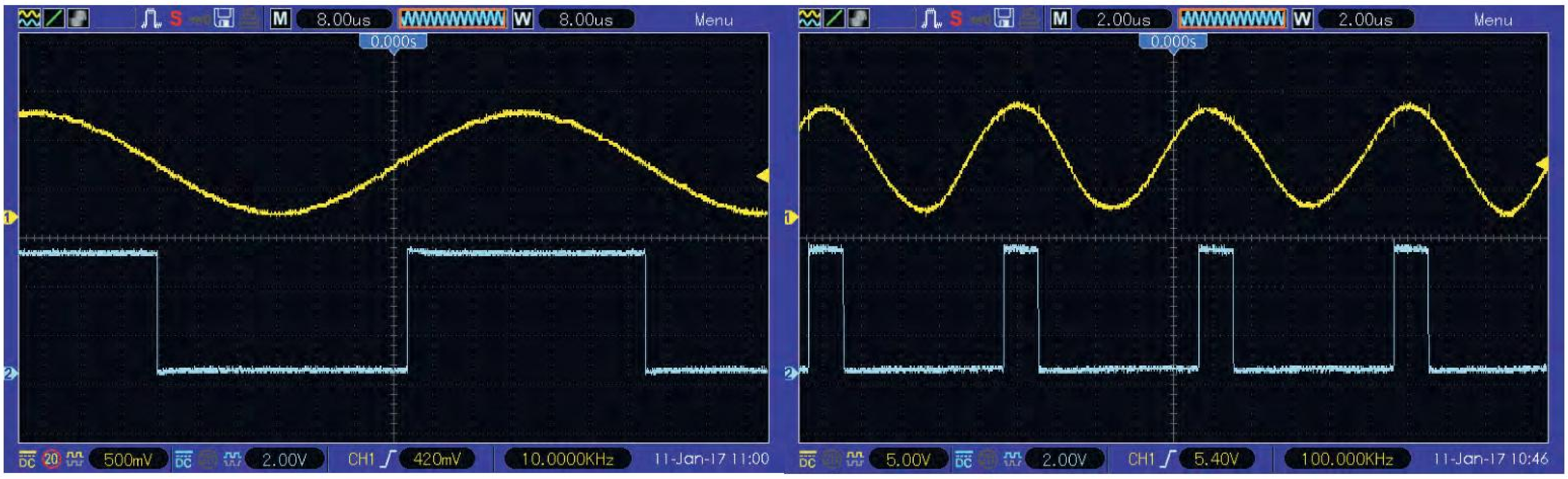

CON1
VCC
D0
D1
D2
D3
D4
D5
D6
D7
GND
10μF
10kΩ
10kΩ
2x 100nF
3x 100nF
6
23
11
18
DVDD DVDD AVDD AVDD
CLKIN
9
D0/LSB
D1
D2
D3
D4
D5
D6
D7/MSB (SDA)
IC1 AD9850
DAC BL
DAC RSET
DAC IOUT
DAC IOUT
3.9kΩ
100Ω
CON2 PIN9
125MHz XTAL OSC
VCC
OUT
NC
GND
1kΩ
LED
A
K
1pF
5.6pF
4.7pF
470nH
390nH
390nH
200Ω
22pF
22pF
22pF
22pF
200Ω
CON2
SCL/W_CLK
SS/FQ_UD
SDA
RST
GND
SQ W +OUT
SQ W –OUT
DAC –OUT
DAC +OUT
IC1 PIN 20
W_CLK
FQ_UD
RESET
COMP VIN+
COMP VIN–
COMP OUT+
COMP OUT–
1kΩ
ADJUST SQ WAVE DUTY CYCLE
10kΩ
100nF
DGND DGND AGND AGND
5
24
10
19
© SC 2017

Fig.2: circuit diagram for the AD9850-based DDS module. Besides the DDS IC and 125MHz crystal oscillator used to derive its output frequency, the main point of interest is the 7th-order low-pass elliptic filter formed by three SMD inductors and a few small ceramic capacitors. This has a corner frequency close to 100MHz and a rapid fall-off, to reject the 125MHz+ switching artefacts from the DAC, while leaving the generated signal largely untouched.



From left to right: 10kHz, 100kHz, 1MHz, 10MHz waveform outputs from the AD9850 DDS module. The 25MHz and 40MHz output graphs are shown opposite.

the pins of CON1 are used for the 8-bit parallel data input (apart from pin 1 for +5V power and pin 10 for ground), while the pins of CON2 are used for the SPI serial interface and the analogue outputs.

Note that pin 25 of IC1 is both D7, the most-significant bit of the parallel input (via pin 9 of CON1) and also the serial data (SDA) line of the SPI interface (pin 4 of CON2).

As shown on Fig.1, the AD9850's DAC has bipolar outputs and these emerge via pins 21 and 20, as shown in Fig.2. But only one of these is actually used within the module – the positive output from pin 21. The signal from this output passes through a low-pass filter formed by the three small inductors and their accompanying low-value capacitors, to remove as much of the DAC noise as possible before the output signal passes to pin 10 of CON2.

The negative DAC output from pin 20 is simply terminated in a 100Ω load and fed directly to pin 9 of CON2, without any filtering. So if you want to use this output, it will need external filtering.

One more thing to note regarding the AD9850's DAC is that its full-scale output current is set by the value of the resistor connected between pin 12 (DAC RSET) and ground. With the 3.9kΩ resistor supplied in the module, the full-scale output current is 10mA, which with the loading of approximately 100Ω gives a DAC output close to 1V peak-to-peak. This should be suitable for the majority of applications.

As well as going to pin 10 of CON2, the filtered positive DAC output is also connected to the positive input of the AD9850's high-speed comparator (pin 16), via a 1kΩ resistor. The negative input of the comparator (pin 15) is fed with an adjustable DC voltage from the 10kΩ trimpot, the ends of which are connected to the +5V power rail and ground.

The trimpot thus provides a simple way to adjust the duty cycle of the rectangular output waveforms derived from the filtered positive DAC output by the action of the comparator. The rectangular outputs emerge from pins 14 and 13, and are taken directly to pins 7 and 8 of CON2.

Note that the comparator outputs are both bipolar and symmetrical, ie, they are always mirror images of each other, regardless of the duty cycle setting set by the 10kΩ trimpot.

Practical limitations

As with the AD9833, the main limitation of this module regards the maximum frequency that it can produce. In theory, this is equal to the Nyquist frequency, or half the sampling clock frequency; in this case, 125MHz ÷ 2, or 62.5MHz.

But you need to bear in mind that because of the way a DDS works, the 'sinewave' that it produces at this frequency will have very high distortion. If you want to get a reasonably smooth sinewave output, this will only be possible at frequencies below about 20% of the clock frequency, or in this case, a maximum of about 25MHz.

If you can tolerate a moderate amount of distortion, it should be possible to get nominal sinewaves at frequencies up to about 40-50MHz. That's why the module pictured is usually advertised as being capable of delivering sinewaves up to '40MHz and above'.

Programming it

Although the AD9850 is capable of being programmed by a parallel loading sequence of five bytes, we're going to concentrate on the SPI interface since it involves only five wires between the micro and the module, rather than the 11 wires needed for parallel loading; with most micro-based projects, it's easy to run out of free pins.

We have summarised the basic coding for the frequency, control and phase registers graphically in Fig.3. The 40 bits making up the serial word are shown in a line along the top of the diagram, with the 32 frequency programming bits (red tint) on the left, followed by the three control bits and the five phase programming bits (blue tint) on the right.

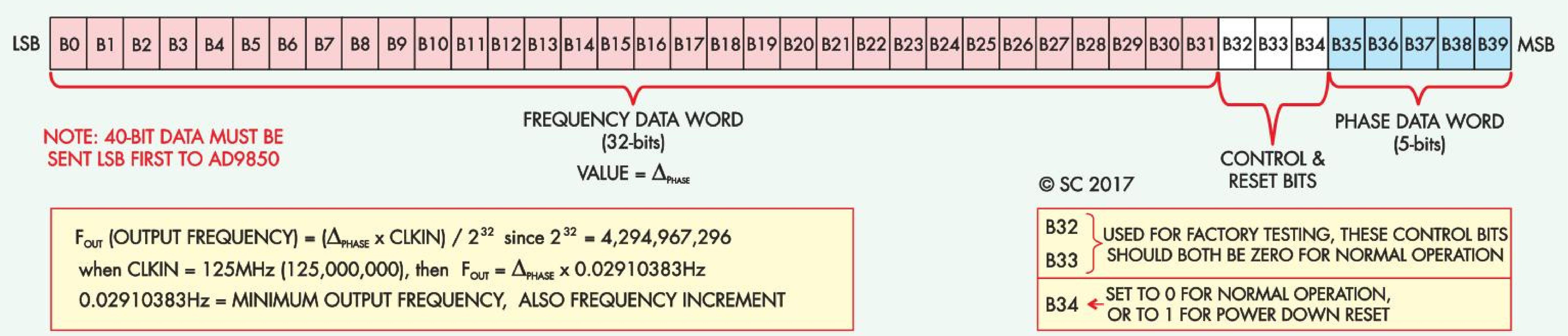
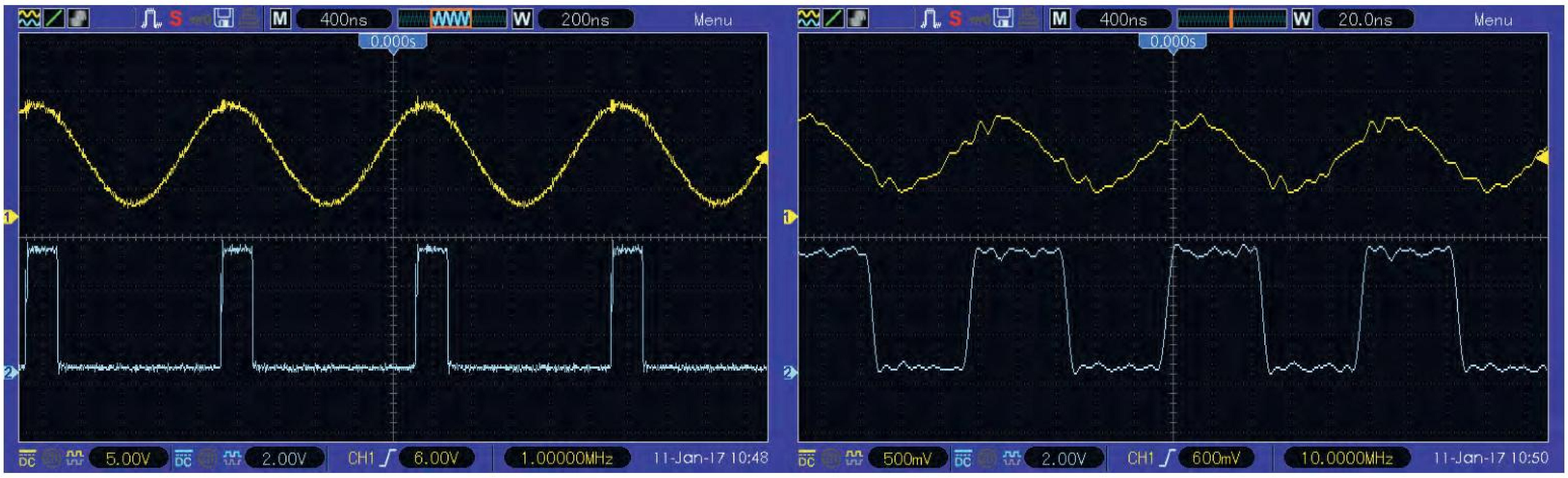

LSB
B0
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
B17
B18
B19
B20
B21
B22
B23
B24
B25
B26
B27
B28
B29
B30
B31
B32
B33
B34
B35
B36
B37
B38
B39
MSB
FREQUENCY DATA WORD (32-bits)
VALUE = Δ PHASE
NOTE: 40-BIT DATA MUST BE SENT LSB FIRST TO AD9850
CONTROL & RESET BITS
PHASE DATA WORD (5-bits)
© SC 2017
F OUT (OUTPUT FREQUENCY) = (Δ PHASE x CLKIN) / 2^32 since 2^32 = 4,294,967,296
when CLKIN = 125MHz (125,000,000), then F OUT = Δ PHASE x 0.02910383Hz
0.02910383Hz = MINIMUM OUTPUT FREQUENCY, ALSO FREQUENCY INCREMENT
B32
B33
USED FOR FACTORY TESTING, THESE CONTROL BITS SHOULD BOTH BE ZERO FOR NORMAL OPERATION
B34
SET TO 0 FOR NORMAL OPERATION, OR TO 1 FOR POWER DOWN RESET

Fig.3: format for loading frequency, phase and control data into the AD9850. 40 bits of data are shifted into the IC, least-significant bit (LSB) first, with the first 32 bits setting the frequency, the next three bits controlling the power-down (sleep) mode and the final five bits setting the phase.


M 400ns
W 200ns
Menu
0.000s
5.00V
2.00V
CH1 6.00V
1.00000MHz
11-Jan-17 10:48
M 400ns
W 20.0ns
Menu
0.000s
500mV
2.00V
CH1 600mV
10.0000MHz
11-Jan-17 10:50

While the AD9850 doesn't provide a direct way to produce a triangle or square wave, a fixed or variable duty cycle square wave can be derived from a generated sinewave plus a DC reference voltage using the internal comparator.

The entire 40 bits must be sent to the AD9850 'LSB first', ie, B0, B1, B2, B3 and so on, right up to B39. When all 40 bits have been shifted into the AD9850's data input register, a short positive pulse is applied to the chip's FQ_UD/SS pin (pin 3 of CON2 in Fig.2), to load the data into the frequency/phase data register.

If you decide to use parallel loading instead of serial loading, the main difference is that you have to present bits B0-B7 to pins 2-9 of CON1 first, followed by a pulse to the W_CLK pin (pin 2 of CON2). Then you repeat this with bits B8-B15, B16-B23, B24-31 and finally B32-39.

Only after all five bytes have been loaded do you then need to apply a short positive pulse to the FQ_UD/SS to load it all into the frequency/phase register.

The formula to determine the DDS output frequency from the 32-bit frequency word is shown at bottom left in Fig.3. With a 125MHz clock and a 32-bit frequency word, the AD9850 has a minimum output frequency of 0.02910383Hz and this is also the minimum frequency increment. So the output frequency $F_{OUT} = \Delta_{PHASE} \times 0.02910383$. Or if you prefer, $\Delta_{PHASE} = F_{OUT} \div 0.02910383$.

For most purposes, you won't really have to worry about the final eight bits of that 40-bit programming word, because as you can see, bits B32, B33 and B34 should be set to zero for normal operation, while bits B35-B39 should also be set to zero if you don't want to perform phase modulation.

So now we just need to connect the module up to our microcontroller. Note that we're only going to do that using the SPI serial interface.

Driving it from an Arduino

There isn't much to it, as shown in Fig.4. Most of the connections can be made via the 6-pin ICSP header. These connections are quite consistent over just about all Arduino variants, including the Uno, Leonardo and Nano, the Freetronics Eleven and LeoStick, and the Duinotech Classic or Nano.

The only connection that's not available via the ICSP header is the one for SS/CS/FQ_UD, which needs to be connected to the IO10/SS pin of an Arduino Uno, Freetronics Eleven or Duinotech Classic, as shown.

With other Arduino variants, you should be able to find the corresponding pin without too much trouble and even if you can't, the pin reference can be changed in your software sketch to match the pin you elect to use.

One thing to bear in mind when you're writing your own sketch to program the AD9850 module is the requirement for the 40-bit programming word to be sent LSB first, instead of the usual MSB first.

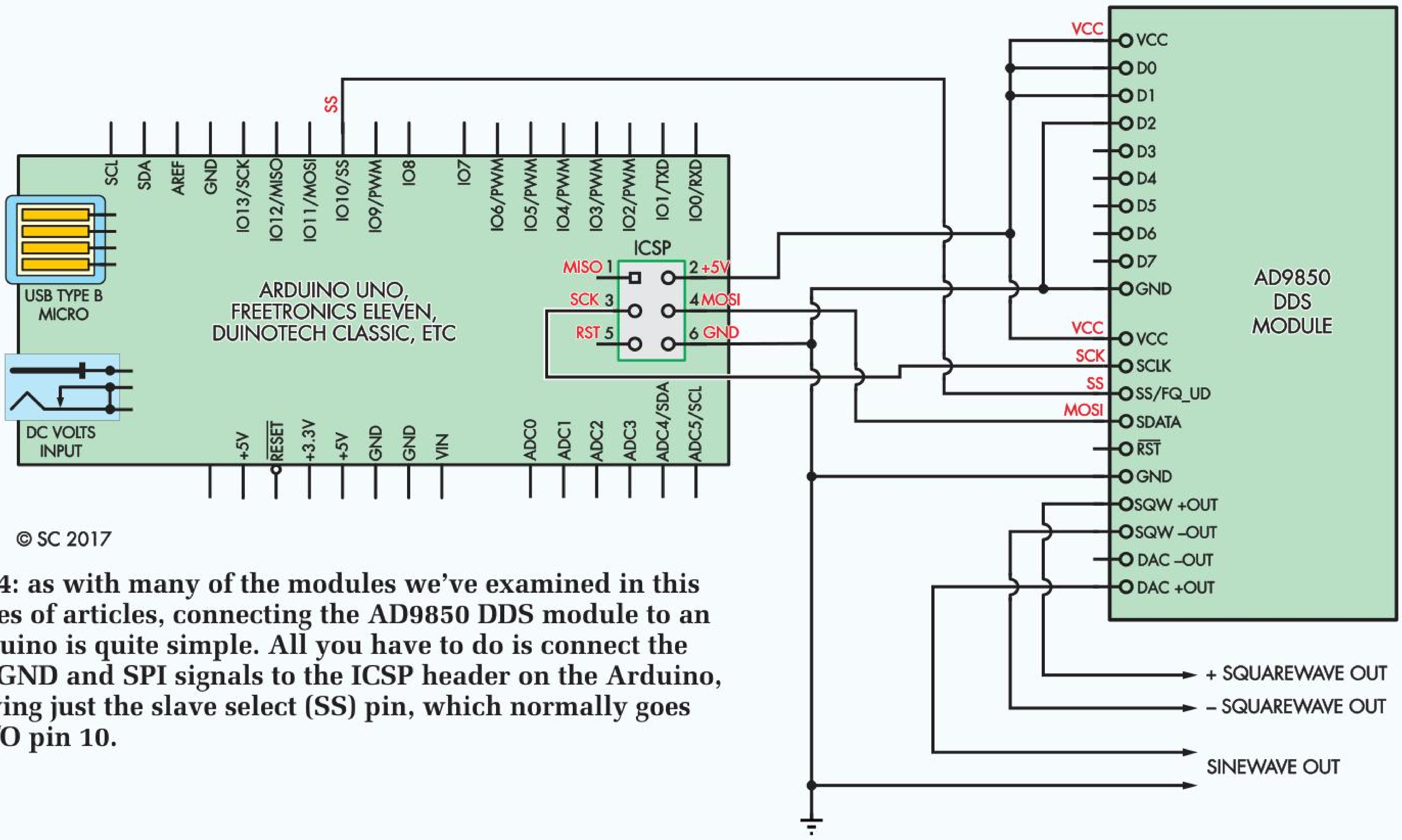
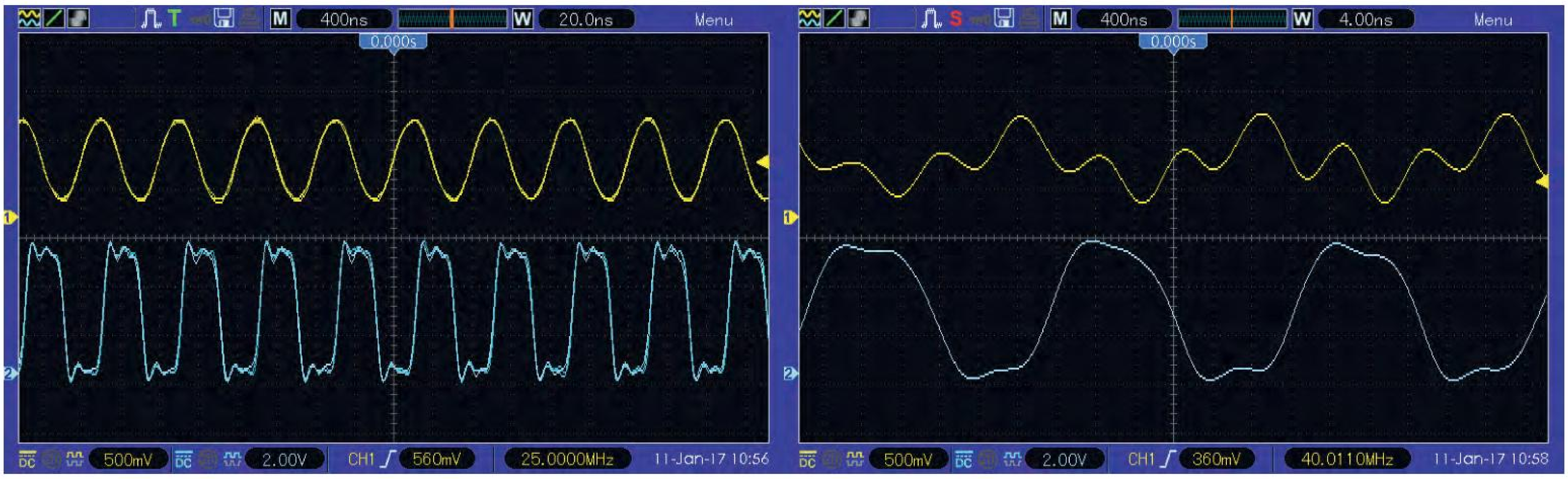

SS
SCL
SDA
AREF
GND
IO13/SCK
IO12/MISO
IO11/MOSI
IO10/SS
IO9/PWM
IO8
IO7
IO6/PWM
IO5/PWM
IO4/PWM
IO3/PWM
IO2/PWM
IO1/TXD
IO0/RXD
ICSP
MISO 1
2 +5V
SCK 3
4 MOSI
RST 5
6 GND
USB TYPE B MICRO
ARDUINO UNO, FREETRONICS ELEVEN, DUINOTECH CLASSIC, ETC
DC VOLTS INPUT
+5V
RESET
+3.3V
+5V
GND
GND
VIN
ADC0
ADC1
ADC2
ADC3
ADC4/SDA
ADC5/SCL
© SC 2017
VCC
VCC
D0
D1
D2
D3
D4
D5
D6
D7
GND
VCC
VCC
SCK
SCLK
SS
SS/FQ_UD
MOSI
SDATA
RST
GND
SQW +OUT
SQW –OUT
DAC –OUT
DAC +OUT
AD9850 DDS MODULE
+ SQUAREWAVE OUT
– SQUAREWAVE OUT
SINEWAVE OUT

Fig.4: as with many of the modules we've examined in this series of articles, connecting the AD9850 DDS module to an Arduino is quite simple. All you have to do is connect the 5V, GND and SPI signals to the ICSP header on the Arduino, leaving just the slave select (SS) pin, which normally goes to I/O pin 10.



You can see that once the frequency exceeds ~25MHz, a fair amount of distortion is introduced into the output.

Note ththe serial data on the SDATA/MOSI line is clocked into the chip on the rising edges of the SCLK pulses and SCLK must idle low, this means you need to set the SPI Settings parameters like this:

```
SPISettings(5000000, LSBFIRST,
  SPI_MODE0)
```

(where that first parameter is the serial clock frequency). Also, since the FQ_UD input of the AD9850 is active high, this line should be programmed to idle in the low state and only go high for loading the data into the AD9850's frequency/phase register.

If this sounds confusing, please refer to the example Arduino sketch I have written; more about this shortly.

Driving it from a Micromite

It's also quite easy to drive the module from a Micromite, using the connections shown in Fig.5. By connecting the MOSI, SCK and SS/FQ_UD lines to Micromite pins 3, 25 and 22 as shown, MMBasic's built-in SPI protocol commands will have no trouble in communicating with the module.

Again, there is just one small complication, brought about by the AD9850's need to have the data sent to it LSB-first.

As MMBasic's SPI commands only have provision for MSB-first data transmission, your program needs to reverse the bit order before it's sent to the DDS.

You'll see one way of doing this in my example program for the Micromite, discussed below.

Note that if you're using the Micromite *LCD BackPack*, because the LCD touchscreen also communicates with the Micromite via its SPI port, your program needs to open the SPI port immediately before it sends commands or data to the module and then close the port again immediately afterwards to prevent any SPI conflicts. This is also illustrated in my example MMBasic program.

Programming examples

The sample program for Arduino is called **sketch_for_testing_AD9850_DDS_module.ino**. This simple program initialises the AD9850, programs it to generate a 100kHz sinewave, then informs you of the current frequency via the Serial Monitor utility built into the Arduino IDE.

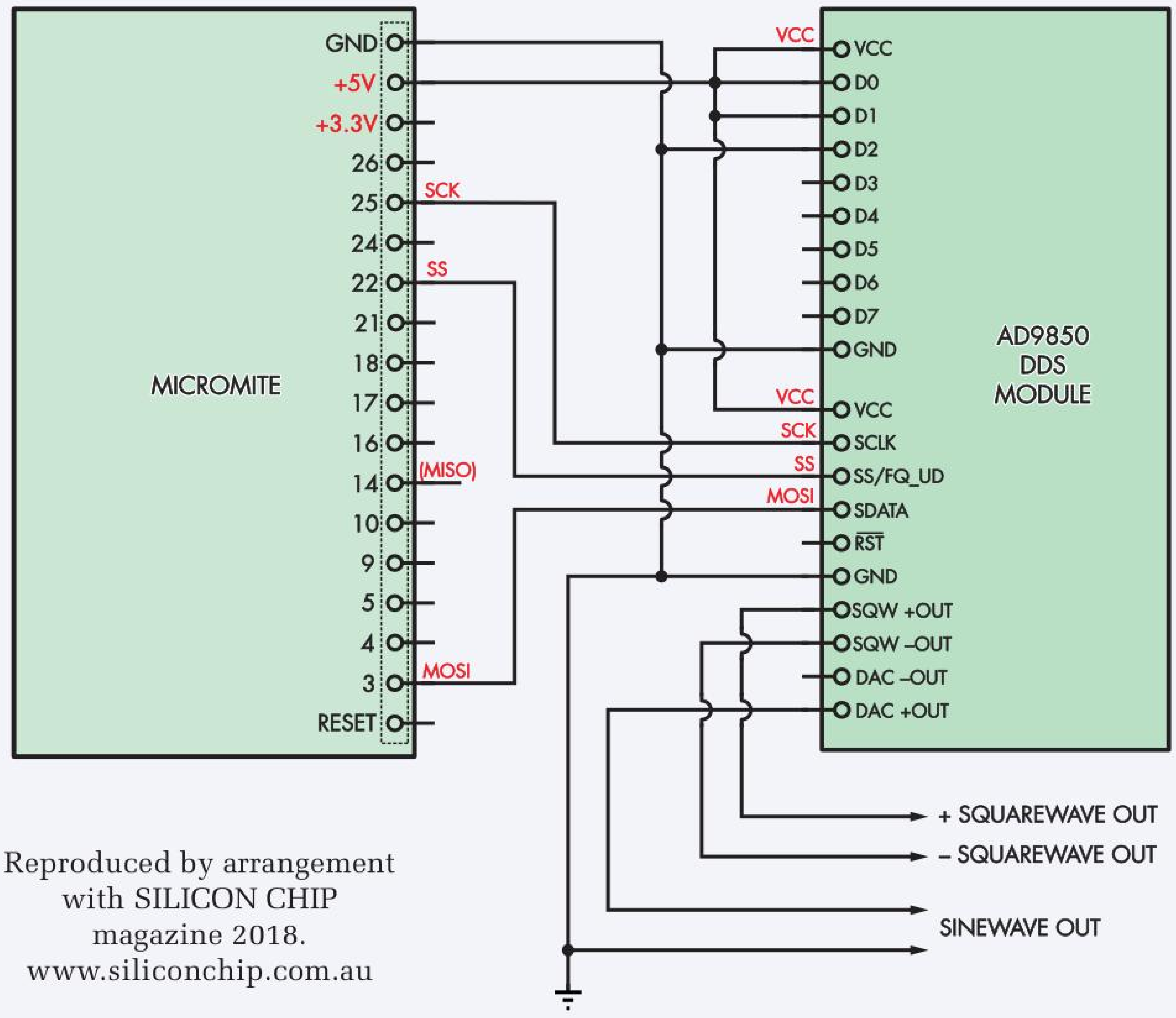
At the same time, it gives you the opportunity to type a new frequency into the Serial Monitor and if you respond by typing in a new frequency and clicking on the Send button, it will load the new frequency into the AD9850 and repeat the process.

It's pretty straightforward, but it should demonstrate the basics of controlling the AD9850 DDS module from an Arduino.

The other program is written for the Micromite *LCD BackPack* and is called **Simple AD9850 sig gen.bas**. This one is a little more complicated, partly because of the need to control the program's operation via the LCD touchscreen and partly because of the need to reverse the bit order of the 40 bits of data sent to the AD9850 because of its LSB-first requirement.

It again lets you control the AD9833's output frequency, in this case by using buttons and a virtual keypad on the *BackPack's* touchscreen. It's quite easy to drive, and again, should show you how the AD9850 can be controlled via a Micromite.

Both of these exanple programs are available for download from the *EPE* website.



Reproduced by arrangement
with SILICON CHIP
magazine 2018.
www.siliconchip.com.au

Fig.5: again, wiring up this module to a Micromite is pretty straightforward. Check the instructions for your Micromite to determine the MOSI and SCK pins; as shown here, for the 28-pin Micromite and *LCD BackPack*, these go to pins 3 and 25. That just leaves 5V, GND and the slave select pin, which in this case we've wired to pin 22.

FANTASTIC MODERN POWER SUPPLY ONLY IU HIGH PROGRAMMABLE

LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£325
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£325

IFR 2025	Signal Generator 9kHz - 2.51GHZ Opt 04/11	£900
Marconi 2955B	Radio Communications Test Set	£800
R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£350
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHZ-20GHZ	£2,000
HP83731A	Synthesised Signal Generator 1-20GHZ	£1,800
HP8484A	Power Sensor 0.01-18GHZ 3nW-10uW	£75
HP8560A	Spectrum Analyser Synthesised 50HZ - 2.9GHZ	£1,250
HP8560E	Spectrum Analyser Synthesised 30HZ - 2.9GHZ	£1,750
HP8563A	Spectrum Analyser Synthesised 9KHZ-22GHZ	£2,250
HP8566B	Spectrum Analsyer 100HZ-22GHZ	£1,200
HP8662A	RF Generator 10KHZ - 1280MHZ	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10KHZ-1.01GHZ	£325
Marconi 2024	Synthesised Signal Generator 9KHZ-2.4GHZ	£800
Marconi 2030	Synthesised Signal Generator 10KHZ-1.35GHZ	£750
Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHZ	£295
Marconi 2945/A/B	Communications Test Set Various Options	£2,000 – £3,750
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHZ-20GHZ	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B with	6910 Power Meter	£295

MARCONI 2955B Radio Communications Test Set - £800

CAN BE SUPPLIED WITH OPTIONAL TRANSIT CASE

PROPER 200MHZ ANALOGUE SCOPE - £250

FLUKE/PHILIPS PM3092 Oscilloscope 2+2 Channel 200MHZ Delay TB, Autoset etc

Tektronix TDS3052B/C	Oscilloscope 500MHZ 2.5GS/S	£1,500
Tektronix TDS3032	Oscilloscope 300MHZ 2.5GS/S	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHZ 1.25GS/S	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHZ 100MS/S	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHZ	£600
Farnell AP60/50	PSU 0-60V 0-50A 1KW Switch Mode	£195
Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
Fluke 97	Scopemeter 2 Channel 50MHZ 25MS/S	£75
Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
Gigatronics 7100	Synthesised Signal Generator 10MHZ-20GHZ	£1,950
Seaward Nova	PAT Tester	£95
Solartron 7150/PLUS	6 1/2 Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160-£200
Thurlby TG210	Function Generator 0.002-2MHZ TTL etc Kenwood Badged	£65
HP33120A	Function Generator 100 microHZ-15MHZ	£260-£300
HP53131A	Universal Counter 3GHZ Boxed unused	£500
HP53131A	Universal Counter 225MHZ	£350

INDUSTRY STANDARD DMM ONLY £325 OR £275 WITHOUT HANDLE AND BUMPERS

HP 34401A Digital Multimeter 6 ½ Digit

YES! AN HP 100MHZ SCOPE FOR ONLY £75 OR COMPLETE WITH ALL ACCESSORIES £125

HP 54600B Oscilloscope Analogue/Digital Dual Trace 100MHZ

STEWART OF READING

17A King Street, Mortimer, near Reading, RG7 3RS
Telephone: **0118 933 1111** Fax: **0118 9331275**
USED ELECTRONIC TEST EQUIPMENT
Check website **www.stewart-of-reading.co.uk**
(ALL PRICES PLUS CARRIAGE & VAT)
Please check availability before ordering or calling in

Teach-In 8 – Exploring the Arduino

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 provides a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project. The projects can be combined together in many different ways in order to build more complex systems that can be used to solve a wide variety of home automation and environmental monitoring problems. To this end the series includes topics such as RF technology, wireless networking and remote Web access.

PRICE £8.99

(includes P&P to UK if ordered direct from us)

FREE CD-ROM
£8.99
ELECTRONICS TEACH-IN 8
FREE CD-ROM
INTRODUCING THE ARDUINO
Teach-In 8
PLUS...

PLUS: PICs and the PICkit 3 - A beginners guide

The why and how to build PIC-based projects. An extra 12 part series based around the popular PIC microcontroller.

FREE COVER-MOUNTED CD-ROM

Containing the software for the two series

ORDER YOUR COPY TODAY JUST CALL 01202 880299 OR VISIT www.epemag.com

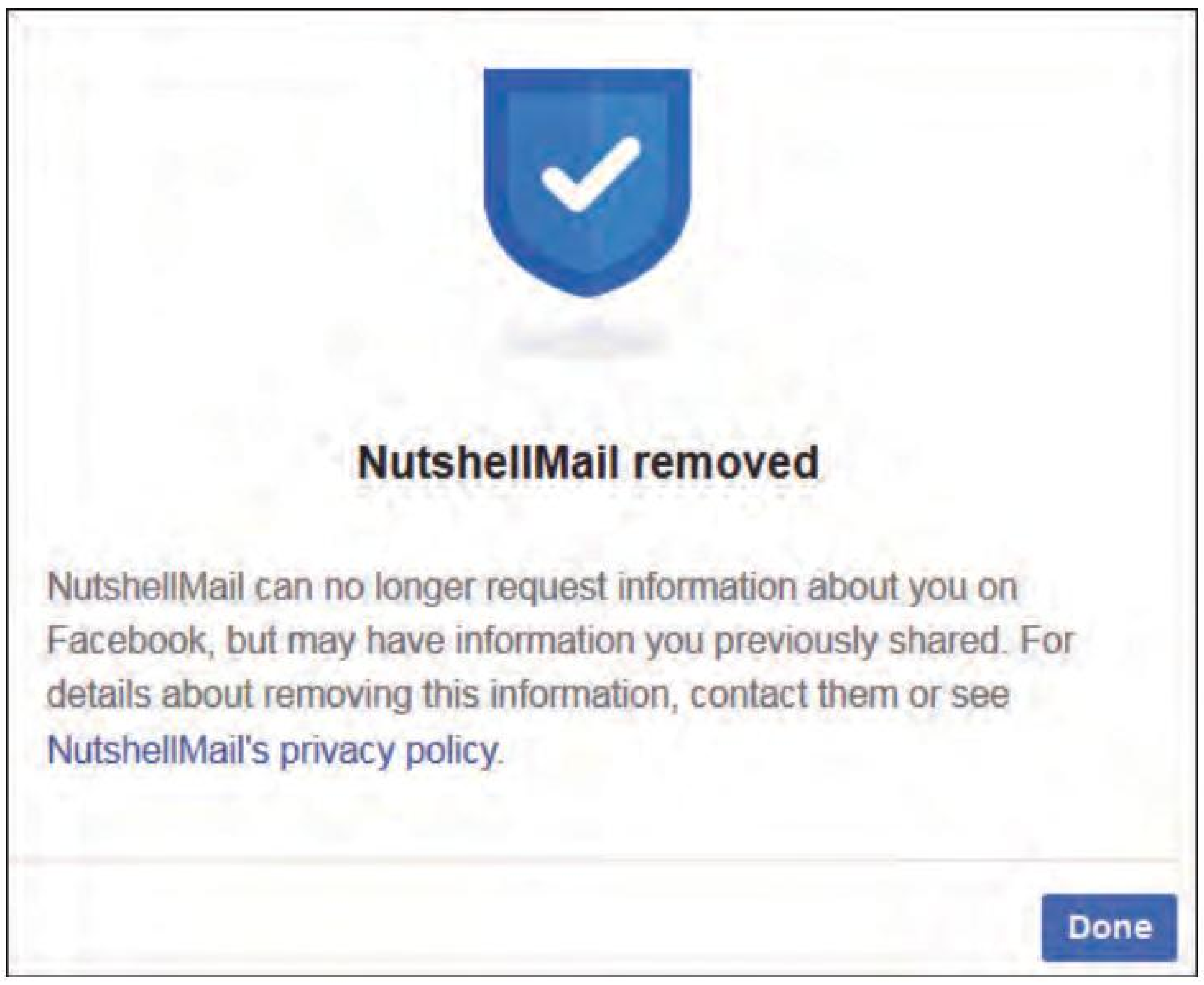
NET WORK

by Alan Winstanley

Your Facebook history

Internet giants such as Facebook and Google are scrambling to meet their users' increasing expectations of privacy and data protection. Facebook offers a quick 'Privacy Check-up' via its Help icon, and its coverage is split into your posts, your profile, and 'Apps & Websites'. Basic options of who-sees-what can be configured here, including the fundamental privacy settings for a user's email address, phone number and date of birth. The section entitled Apps & Websites lists third-party websites that you logged into seamlessly using your Facebook account. In my case, I barely remembered some third-party websites that I was told I had logged into in the past. Deleting a third-party's Facebook privileges (screenshot below) creates another quandary, as cautious users would have to contact each website individually to delete private data that had been shared with them via Facebook.

You can access more details, including 'expired' Apps & Website privileges via Facebook's Settings menu. Other options worth investigating include Locations Settings; Facebook claims that your location history is private and only you know it, but of course Facebook knows it as well. You can purge this history from Facebook if desired. Also check if Face Recognition is enabled. For example, if someone uploads a football team photo that includes your mug shot then Facebook can try to 'read' the facial images and literally put a name to a face (yours). If you disable this feature then you won't be tagged like that – nor, says Facebook, would you be notified if, for example, a fraudster impersonated you by building a bogus Facebook profile containing your image (unlikely, but you never know). Users can weigh up the benefits and risks for themselves and Facebook offers more details at: **www.bit.ly/2KkkPX9**



NutshellMail removed

NutshellMail can no longer request information about you on Facebook, but may have information you previously shared. For details about removing this information, contact them or see NutshellMail's privacy policy.

Deleting a legacy app from within Facebook: NutshellMail was a social network aggregator service that sent an email digest of social networking updates

Google account holders can run their own privacy check-up by logging into **https://myaccount.google.com/privacycheckup**. I found the whole 'check-up' experience similar to that seen on Facebook, a deceptively minimalist design peppered with simplified graphics and captions supposedly intended to reassure users. It left me thinking that I must be missing something somewhere. Google gathers so much data that it is hard to know where to start, but the Google MyActivity link (jump direct to: **www.bit.ly/2tIsaFk**) sheds light on a Google Account holder's history. Depending on which Android version is running on a mobile device, options for location history, device information and Web & App activity can be paused or deleted here, but one's Google Search history can also be erased via a web browser's History settings – but even then, how can one be sure that it is gone for good? More than anything, Facebook's and Google's efforts to reassure users about their privacy highlighted the industrial scale of information that is being captured behind the scenes.

A YouTube dilemma

Google MyActivity also listed almost every YouTube video that I had watched since the year 2014. Admittedly, I don't mind YouTube's attempts to second-guess what YouTube videos might appeal to me based on my video watching history. Of course, YouTube isn't just about corny home video clips; it also hosts a plethora of documentaries, political shows, debates, TV programmes as well as a recent demo by *EPE's* Mike Hibbett of his *PIC n' Mix* spectrum analyser using a PIC microcontroller. There is usually something to interest everyone – but how to get the best out of YouTube?

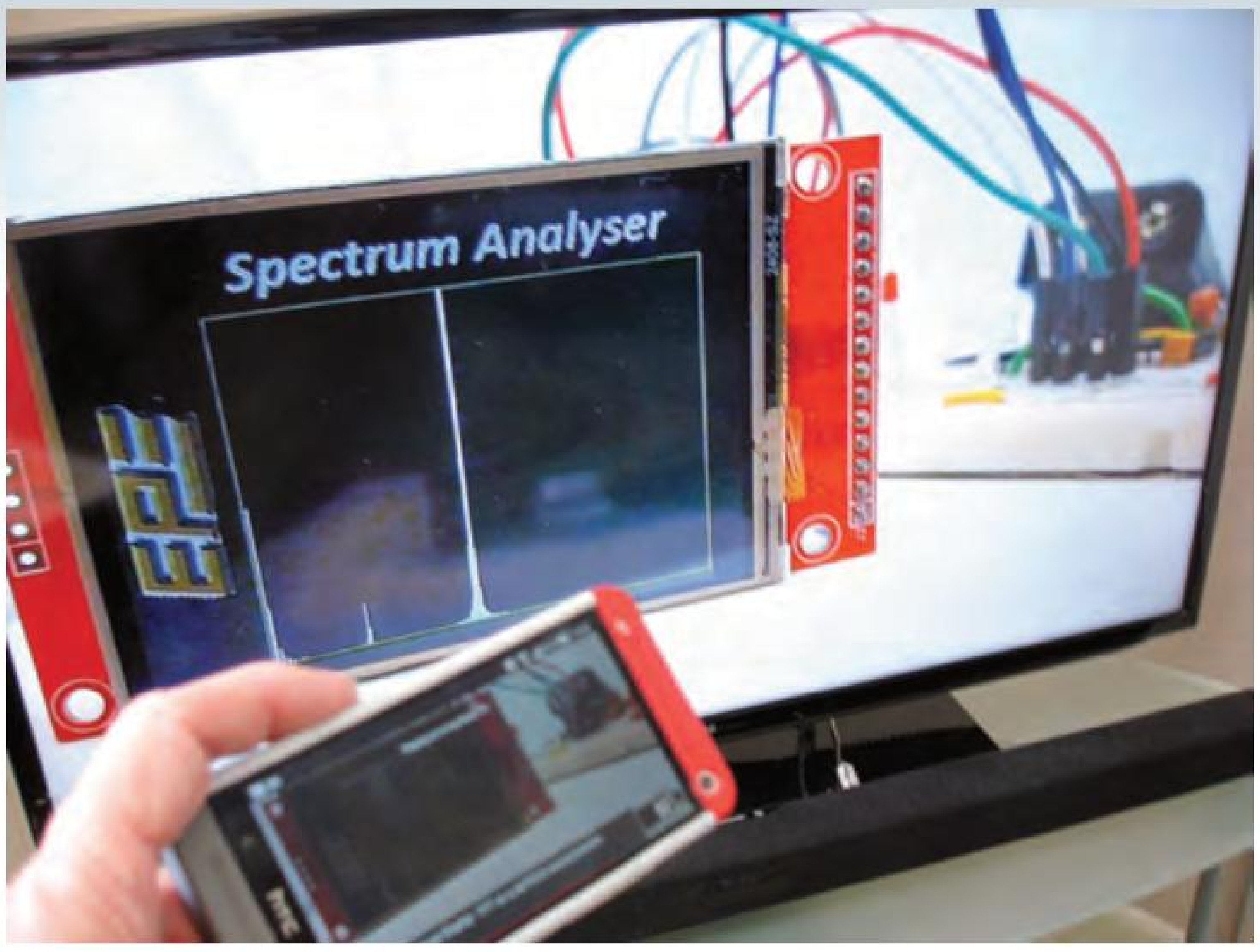
While the video sharing site can be viewed directly in a web browser, many 'smart' TVs and PVRs also have YouTube apps built in, but future compatibility and support for them is far from certain. As regular *Net Work* readers might recall, the writer's Samsung smart TV had to drop its YouTube app when the latter's format changed to HTML5. Likewise, a variety of Amazon Fire or Echo devices have ceased to run YouTube directly, and although a Humax HDR Freeview recorder recently purchased by the writer handles YouTube natively, its elder sibling, the Humax HDR Fox-T2 PVR, no longer does.

I tried the Amazon Fire TV Stick last year – this HDMI dongle adds some 'smarts' to a TV or HDMI monitor, but it too dropped YouTube support for 'commercial reasons'. The most seamless way of viewing YouTube on a big screen is probably by using a Google Chromecast HDMI dongle (typically £30), so one of these was recently tested on the family TV. The Chromecast is a small puck-shaped object on a long-reach, rubbery HDMI lead and requires yet another 5V switched-mode power adaptor (included). The dongle then proceeded to set itself up using Google Account details and it connected to a nearby Devolo Wi-Fi repeater successfully, after which the Chromecast updated itself over the wireless LAN.

Chrome plated

Google claims Chromecast works with Android, iPhone, Windows and Mac devices, so the Google Home app

The Chromecast HDMI dongle needs a 5V USB-type supply (included)



Google Chromecast lets you 'cast' YouTube videos from a smartphone or tablet app onto an HDMI TV or monitor – shown here, Mike Hibbett's recent PIC n' Mix spectrum analyser using a PIC microcontroller, as shown on YouTube.

installed on an Android phone and tablet and the dongle was detected. It was commendably simple to use the smartphone app as a 'remote' to search and queue YouTube videos and 'cast' them for sharing on the full screen TV, including Mike's PIC demo (photograph). So far, Chromecast has proven much more productive and reliable than the legacy Samsung YouTube app that rarely paired properly with the smartphone. The Chromecast also adds catch-up TV, Netflix, BT Sport, Spotify, Facebook and more – unless they stop supporting them, that is. More Chromecast-enabled apps are shown at **http://g.co/chromecast/apps**. It also opens up the world of home control using Google Assistant, a project that is in the pipeline!

Advertisements are part and parcel of Google's YouTube package; they can annoy and distract, but it's what keeps YouTube free. Ardent music and video users might like the new Youtube Premium service that was recently soft-launched by Google. Formerly known as YouTube Red, this paid-for service could finally swing the balance for surfers who want to enjoy their music and video without those intrusive adverts. A $9.99 monthly subscription gets access to YouTube Music Premium with downloadable ad-free music to compete with Spotify, while for $11.99 / £11.99 YouTube Premium bundles in ad-free YouTube video that can also be downloaded for offline viewing. At the time of writing, a free three-month trial was available. More details at: **www.youtube.com/premium**

See you next month for more *Net Work*. The writer can be emailed at: **alan@epemag.net**

Electronics & Robotics for Makers

ICSAT's *Pixie* system for Education and Hobbyists now adds ATTiny based mainboards to the PICAXE and Genie based versions.

Pixie 8 & 14 mainboards, simple standalone boards that provides one or two standard ***Pixie*** port connectors for power and I/O connections. PICAXE and Genie versions have the 3.5mm download socket and the ATTiny versions have the ATMEL 6 pin ICSP programming connector.

Pixie ATTiny programmers, we have two versions. One that is a mini shield for the Arduino Uno complete with 6 pin ICSP connector. The second one is a complete unit based upon the Arduino Nano, which is pre-programmed and ready to go, you just need to update your Arduino IDE, with the ATTiny board information.

Pixie Sprite is a complete module with I/O connections and 2 bidirectional motor outputs powered by an L293D, and is available in all 3 chip types: PICAXE, Genie and Attiny84. The board can use crocodile clips and 1 pin headers for use with jumpers - a great solution for education and Robotics.

The ***Pixie*** 8 and 14 pin mainboards have one or two ***Pixie*** ports which provides power and I/O connections, all our ***Pixie Dot*** and ***Pixie Hot*** project boards are fully compatible with them.

Supporting Education
Supporting *Makers*
ICSAT
www.eshop.icsat.co.uk

ESR Electronic Components Ltd

All of our stock is RoHS compliant and CE approved. Visit our well stocked shop for all of your requirements or order on-line.

We can help and advise with your enquiry, from design to construction.

3D Printing • Cable • CCTV • Connectors • Components • Enclosures • Fans • Fuses • Hardware • Lamps • LED's • Leads • Loudspeakers • Panel Meters • PCB Production • Power Supplies • Relays • Resistors • Semiconductors • Soldering Irons • Switches • Test Equipment • Transformers and so much more…

Monday to Friday 08:30 - 17.00, Saturday 08:30 - 15:30

Station Road
Cullercoats
North Shields
Tyne & Wear
NE30 4PQ

Tel: 0191 2514363 sales@esr.co.uk www.esr.co.uk

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICMeter Part 1 – Introduction to the Voltmeter

LAST month, we had a look at the PICkit 4 programmer and debugger; while it is an interesting device with some great new ideas, we are going to stick with the PICkit 3 programmer for the foreseeable future. We will keep a close eye on how the PICkit 4 develops and return to it when some of the more interesting features are enabled and we know its initial bugs have been straightened out.

This month, we're going to start a new project: the *PICMeter*, a PIC-based multimeter. Just like projects we've built in the past, this will be an exploratory project that will grow as we add extra features. We'll treat it as an agile software design; each article will add a working functional part. We will alternate between the hardware and the software aspects of PIC development along the way.

The plan is to start the project build on a breadboard to give us a feel for what we want, find out which is the right PIC and get a rough idea of how big the circuit is going to get. When we have a good idea of what we will be adding, we will develop a PCB, probably using Autodesk's Eagle CAD. The free version allows one schematic page and a two layer PCB of $120cm^2$ area. I've used Eagle CAD for the last few years, and ever since Autodesk acquired it there has been a marked improvement in the feature set and support for the product. It's no Altium or OrCAD, but for the hobbyist market, it is a really powerful free tool.

Features wish list

The modern digital multimeter is a combination of several measurement tools, including voltmeter, ammeter and ohmmeter. As we progress with the *PICMeter* project, we will look at and consider various methods of performing the typical measurements that multimeters undertake. In high-end systems these tools still exist as standalone instruments for very precise measurements, but a good modern multimeter is perfectly acceptable for most work.

It's important to be clear from the outset that we are not looking to compete with the best of the digital multimeters on the market. The objective here is to learn to use PICs, not create Hewlett-Packard standards of instrumentation. Nevertheless, our *PICMeter* should be capable of performing useful and accurate measurements.

So, what multimeter features can we add to a PIC project without getting overly complicated but still using as many features of the PIC as possible? Let's start with some *PICMeter* 'must haves':

- DC voltmeter: 1mV to 20V
- DC ammeter: 10µA to 2A
- Ohmmeter: 1Ω to 1MΩ
- AC voltmeter and ammeter
- Diode checker
- Continuity checker (buzzer)

If we have the time, PCB space and PIC capability then a few nice extras might include:

- Frequency
- Counter/timer
- Temperature
- NPN and PNP bipolar transistor h_{FE} gain checker
- Reactance measurement, including inductance, capacitance and ESR

The *Teach-In 2018* series has covered some of these as modular test tools. However, our focus will be on learning to use the internal features of a modern PIC. With that in mind, there are four main components we need to build to create our *PICMeter*:

- PIC
- Screen
- Power supply (battery)
- Buttons.

Display and buttons

Many traditional multimeters use variants of the classic 4-digit, 7-segment display. However, they're surprisingly pin heavy and lack flexibility. It's actually easier, less complicated and less expensive to use a small 2.2-inch TFT LCD display. And let's face it, they look nicer.

Adding some push buttons gives us the means to talk to the *PICMeter's* PIC and will allow different options to be selected (and displayed on the LCD screen).

PIC selection

Picking PICs is tricky! Hopefully, we'll select a good microcontroller from the outset, but just in case we get stuck down a PIC dead end we won't commit ourselves to a finished PCB just yet. Instead, we'll use the flexibility of building on a breadboard where we can spend a few months verifying, tweaking and fine-tuning our choice(s). When we are happy with our design we'll graduate to a dedicated PCB.

Having some idea of our target features greatly aids the challenging task of selecting the right PIC for the project. It does help to get a PIC with a few extra pins and features, just in case we want to add functions. There's no need to limit ourselves here, but also there's no point in going completely over the top. I'm going to start with a mid-range 16-bit PIC – the PIC24FV16KM202, which provides plenty of interesting options, including:

- 8-bit DACs
- Op amps
- 10/12-bit ADCs
- Analogue comparators
- CTMU
- Voltage range from 2.0V to 5.0V

This device also has a band gap voltage reference, which can be used with the ADC to improve input accuracy. These are just a taste of some of the internal PIC features, we will be using over the next few months. As you can see, it's quite a sophisticated device and a definite step up from the simpler 8-bit devices we have used in the past.

First function – DC voltage measurement

One of the easiest functions to start off with is the DC voltmeter (we'll come to AC measurements later). Measuring a voltage between zero and the operating voltage is easily done using an analogue-to-digital convertor (ADC), which we have covered multiple times in the past. A 0-5V input fed to a 12-bit ADC means we can achieve a resolution of 5V / 4096 = 1.22mV, which is pretty impressive.

What about voltages outside the 0-5V comfort zone? Some multimeters can measure up to 1000V, but that's a bit high for a project like this. I'd like to be able to measure the voltage of a 9V PP3 alkaline battery or maybe a 12V car battery, so a maximum measureable input voltage of 20V should be sufficiently high to meet most requirements.

To measure voltages greater than the operating voltage of the microcontroller we need to use a voltage divider circuit. Older multimeters would use a number of resistors and a rotary switch to choose between several voltage dividers and thereby obtain an input voltage in a range that could be measured by the multimeter.

Fig.1 shows this manual selection topology. As the wiper on the input is changed between the four resistor inputs, the voltage is divided based on the selected resistor. The voltage measured at the input is calculated by:

$$V_{out} = (V_{in} \times R_1) / (R_1 + R_X)$$

Here, R_X is the selected input resistor (R_2 to R_5). Let's consider the following options:

R_1 = 1kΩ
R_2 = 100Ω
R_3 = 1kΩ
R_4 = 10kΩ
R_5 = 100kΩ

Using the divider equation, and an input voltage of 20V, R_2 gives an output voltage of 18.182V, R_3 gives 10V, R_4 gives 1.818 and R_5 gives 0.198V. Both R_2 and R_3 produce voltages that are too high for our PIC to measure, but R4 and R_5 give in-range values that can be measured.

This circuit does have one drawback; it assumes we will be connecting the common or negative input to the ground on another system. This means we won't be able to detect negative voltages, a problem we will return to later.

Digital potentiometer

Taking an alternative approach with fewer components, let's try and perform the switching process automatically using a digital potentiometer. The MCP4151-104 from Microchip is a 100kΩ, single 8-bit digital potentiometer with an SPI interface and volatile memory. '8-bit' means there are $2^8 = 256$ resistors internally, which can be digitally selected to provide the selected voltage divider. In truth, 256 resistor steps is a little excessive, we probably won't use all of them, but it does offer a good range of resistor values in a single package, and with some careful software coding it will protect the microcontroller from over-voltage situations.

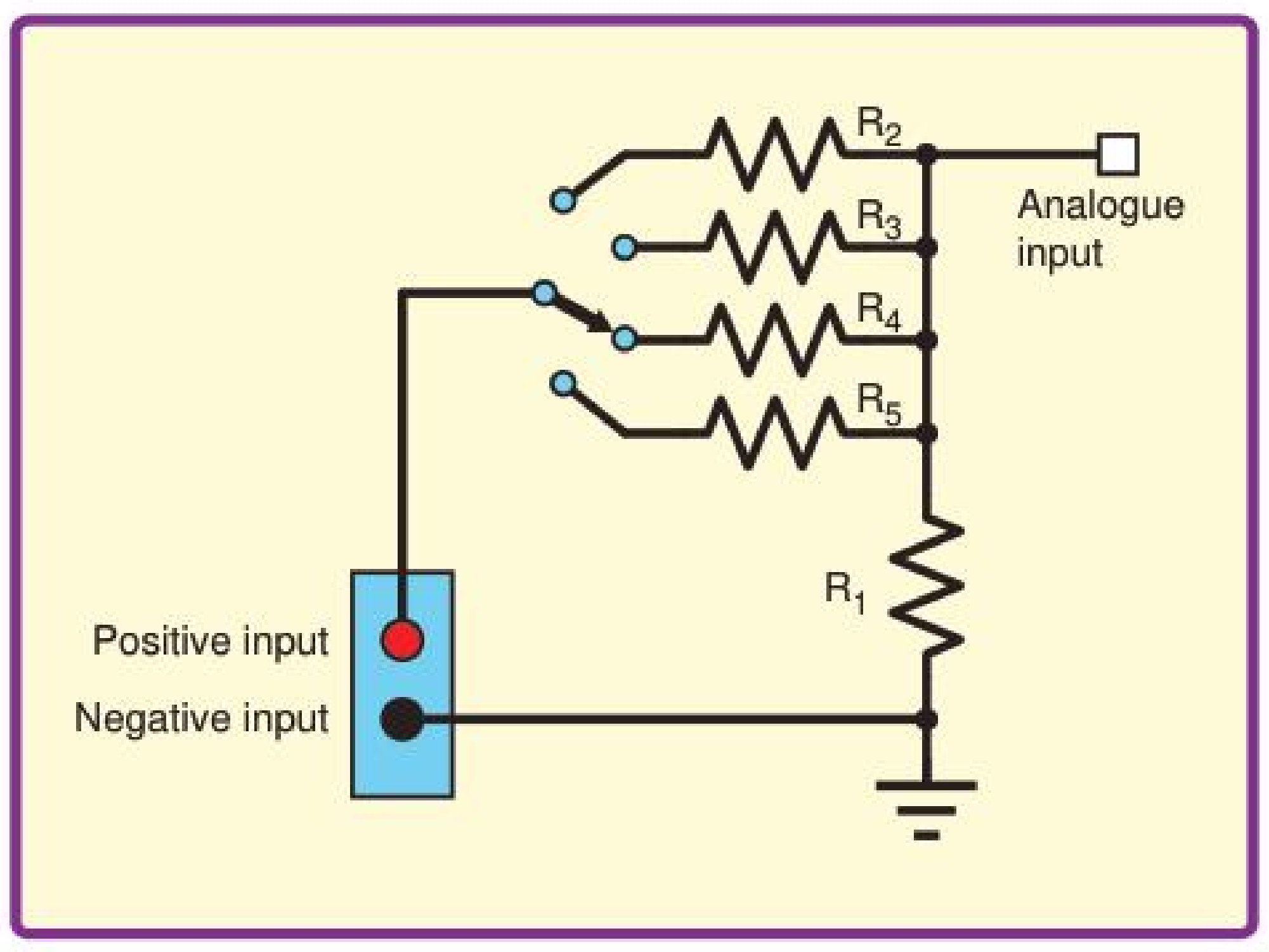


Fig.1. Manual voltage divider selection using rotary switch

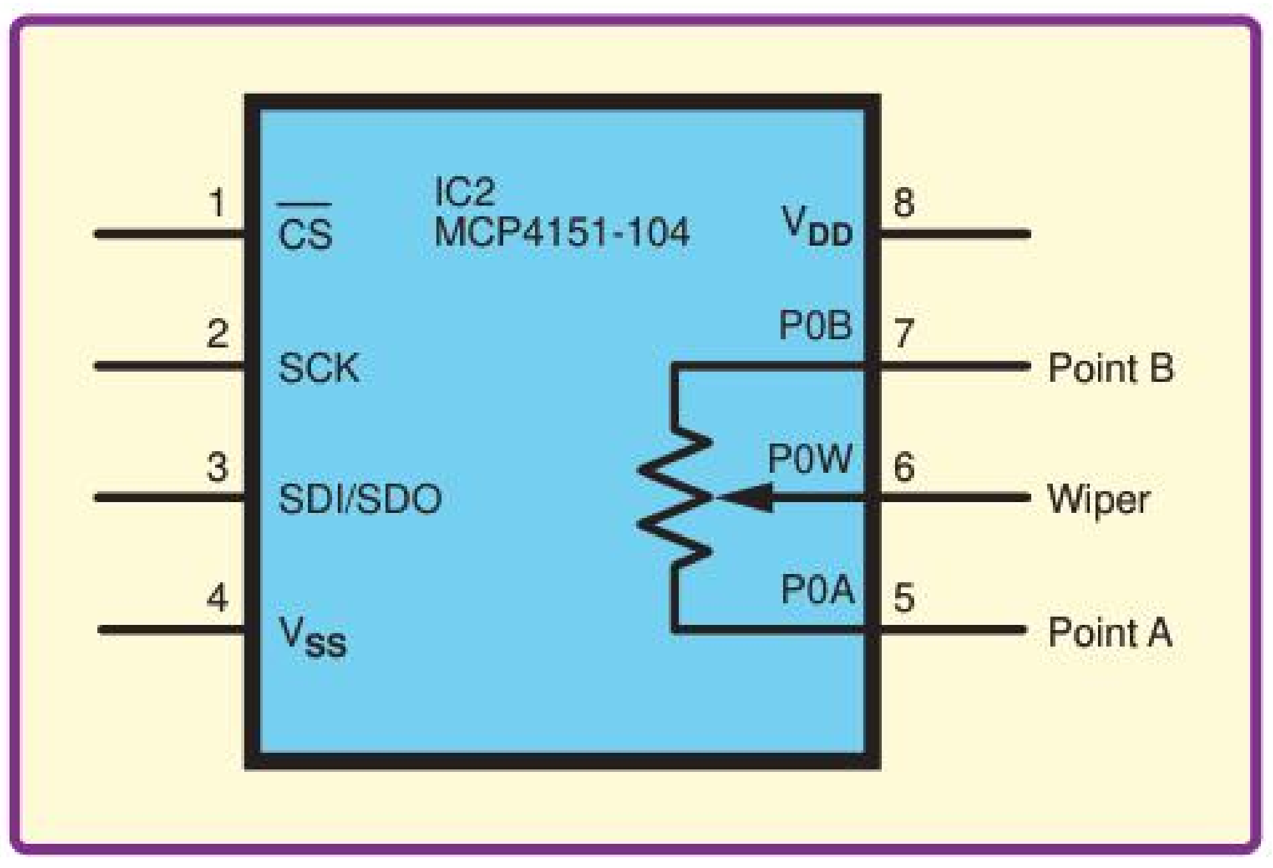


Fig.2. Internal connections of the MCP4151 8-bit digital potentiometer

Fig.2 shows the digital potentiometer's basic pinout. Just like a physical potentiometer, there are two main poles (A and B), plus a centre wiper. Digital commands (from the PIC) control the wiper, which steps through the resistances between points A and B. The datasheet says that point B is set to be at full range from the wiper at 100kΩ.

There are three possible potential divider options we can use here, as shown in Fig.3 (VR1 is the digital potentiometer). Option 1 is the simplest and superficially the most attractive, but there's a hitch. The MCP4151's absolute maximum ratings dictate that each of the potential divider pins can only handle a maximum voltage of V_{DD} + 0.3V compared to V_{SS}. If V_{DD} is 5.0V, then the maximum voltage allowed on any pin is 5.3V. In other words, the digital potentiometer can only handle the same maximum input voltage as the PIC, which unfortunately defeats the whole point of having a voltage divider on the analogue input. Likewise, Option 2 also risks over-voltage if, for example, the potentiometer input connection is 20V and we want the other end to deliver 5V to the PIC.

This leaves us with Option 3, which fortunately looks much more hopeful. In this case, the digital potentiometer is effectively 'in parallel' with the PIC, so with the right potential divider design it won't see an excessive voltage.

So, what resistance ratio should we use? Our specification is that with a maximum input of 20V the PIC should see no more than 5V, which gives us an easy divider ratio of 4:1. Using our divider equation we get:

$$20 \times VR1/(VR1 + R_1) = 5$$

A little rearranging results in $R_1 = 3 \times VR1$

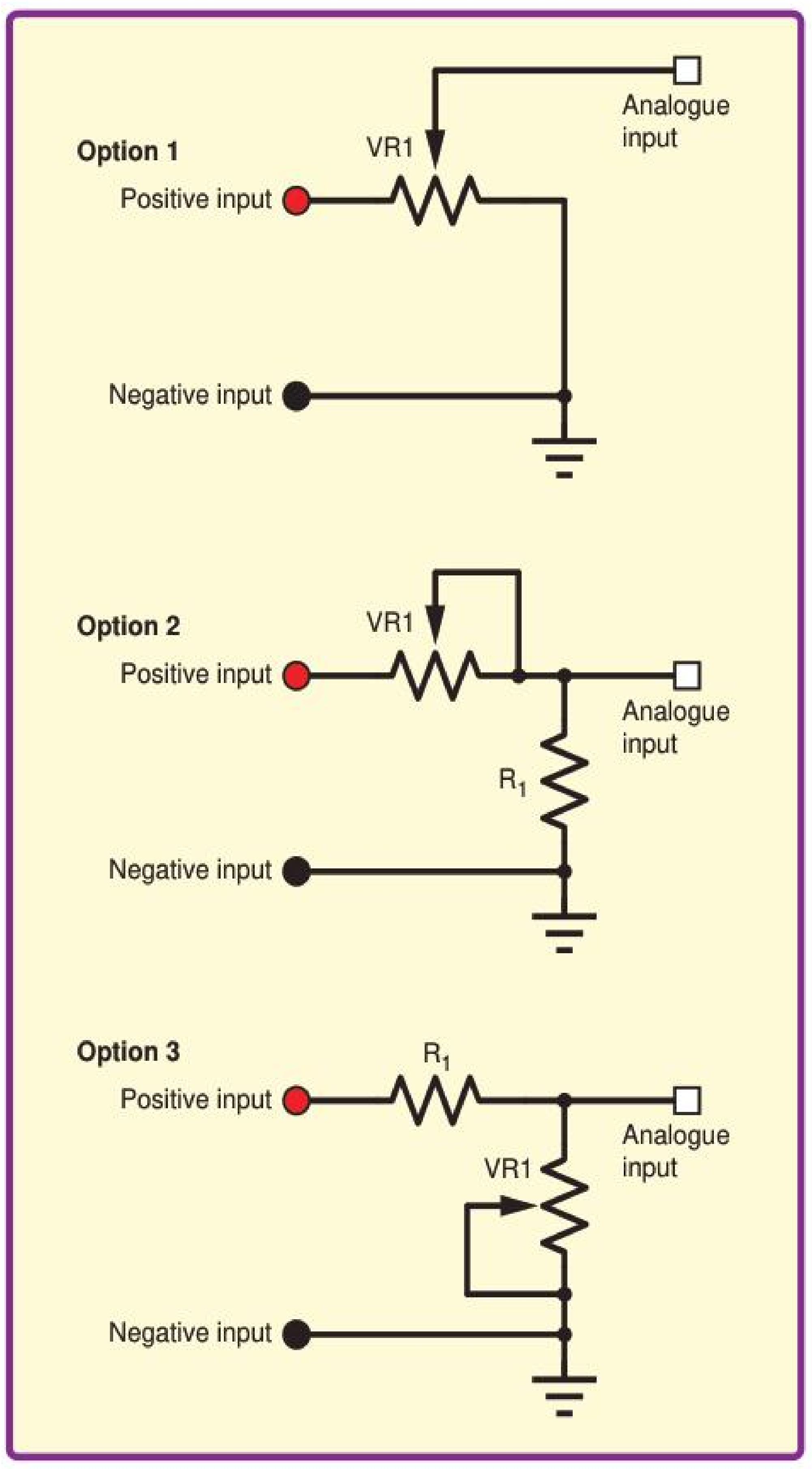


Fig.3. Input voltage divider options

We know our digital potentiometer is 100kΩ divided into 256 steps, so each step is equal to 390Ω. Let's use the first 10 steps, giving a resistance of 3.9kΩ. Next, calculate the fixed resistor value; $R_1 = 3 \times 3900 = 11.7$kΩ, for which the nearest E24 value is 12kΩ.

Now, check the power rating of the fixed resistor. If the whole maximum input voltage of 20V were to appear across the resistor then the power dissipated would be given by:

$$P = V^2/R = 20^2/12000 = 33\text{mW}$$

Typical through-hole resistors have a maximum power dissipation of 1/4W (250mW), so in this application 12kΩ is easily within the thermal safe operating area.

What would happen if the maximum input voltage were safely within our 5V range? In this scenario we wouldn't want to attenuate the voltage – that would simply degrade the circuit's precision. The answer is to push the potentiometer up to 100kΩ; and now, most of the whole input voltage appears at the PIC's analogue input. To be precise, the attenuation by the divider is given by: 100 / (100 + 12) = 0.89.

Four important points should be mentioned here. First, since we know what the attenuation is, its effect can easily be corrected in software. Second, by ramping up the value of the potentiometer we don't lose valuable resolution for small signals. Third, what about the input impedance? 100kΩ is not exactly ideal for measuring small, delicate, noise-prone signals, so the design probably needs to include a buffer.

Fourth – how does the circuit know what the input voltage range will be? How is the potential divider ratio chosen? This and other questions will be addressed next month!

Last, I mentioned the band gap reference earlier. This is an internal reference voltage, which can be used for improving ADC accuracy. The band gap reference voltage is 1.024V. With a 12-bit ADC, the resolution is now 0.25mV. This allows us to measure much lower voltage inputs, without losing accuracy and will be covered in greater detail in the software overview next month.

First PIC design

Before signing off this month let's make a start on the actual circuit. Fig.4 shows the schematic for our basic DC voltmeter. There are only four parts:

- PIC24FV16KM202-I/SP
- MCP4151-104
- 0.1-inch, 6-pin header for the PICkit 3
- 10kΩ through-hole resistor

This circuit connects up the basic components to program/debug the PIC, and communicate with the digital potentiometer over SPI and of course the voltage measurement inputs. You may notice we have forgone the typical necessary decoupling capacitors. As the circuit grows, we will add the correct capacitors and protection circuits for the device. All V_{DD} pins should be decoupled with a 100nF capacitor and a suitable reverse-biased Zener diode should be attached to the input of the ADC to protect the pin from over-voltage situations. We'll discuss these additions more as we build up our circuit.

Fig.5 shows the breadboard version of the schematics. At the moment, there is no screen or method to determine the value measured on the input, other than programming the PIC in debug mode and reading the ADC register after each measurement. This will have to be added next month.

Next month

For the first few months, we'll stick to the breadboard, slowly building up our design. When we are confident that we have ironed out most of the initial challenges we will start designing and populating our own custom PCB. (The components for the PCB will be either through hole or easy to solder for all abilities.)

Over the next few issues we'll add all sorts of exciting functions, using some of the more advanced features of the PIC24F microcontrollers.

Next month, we will look at the screen and start writing the core software, which we will build on each month. The display will be a 2.2-inch TFT SPI 240 × 320 screen using the ILI9341 display controller. These can be bought on eBay for around £8.

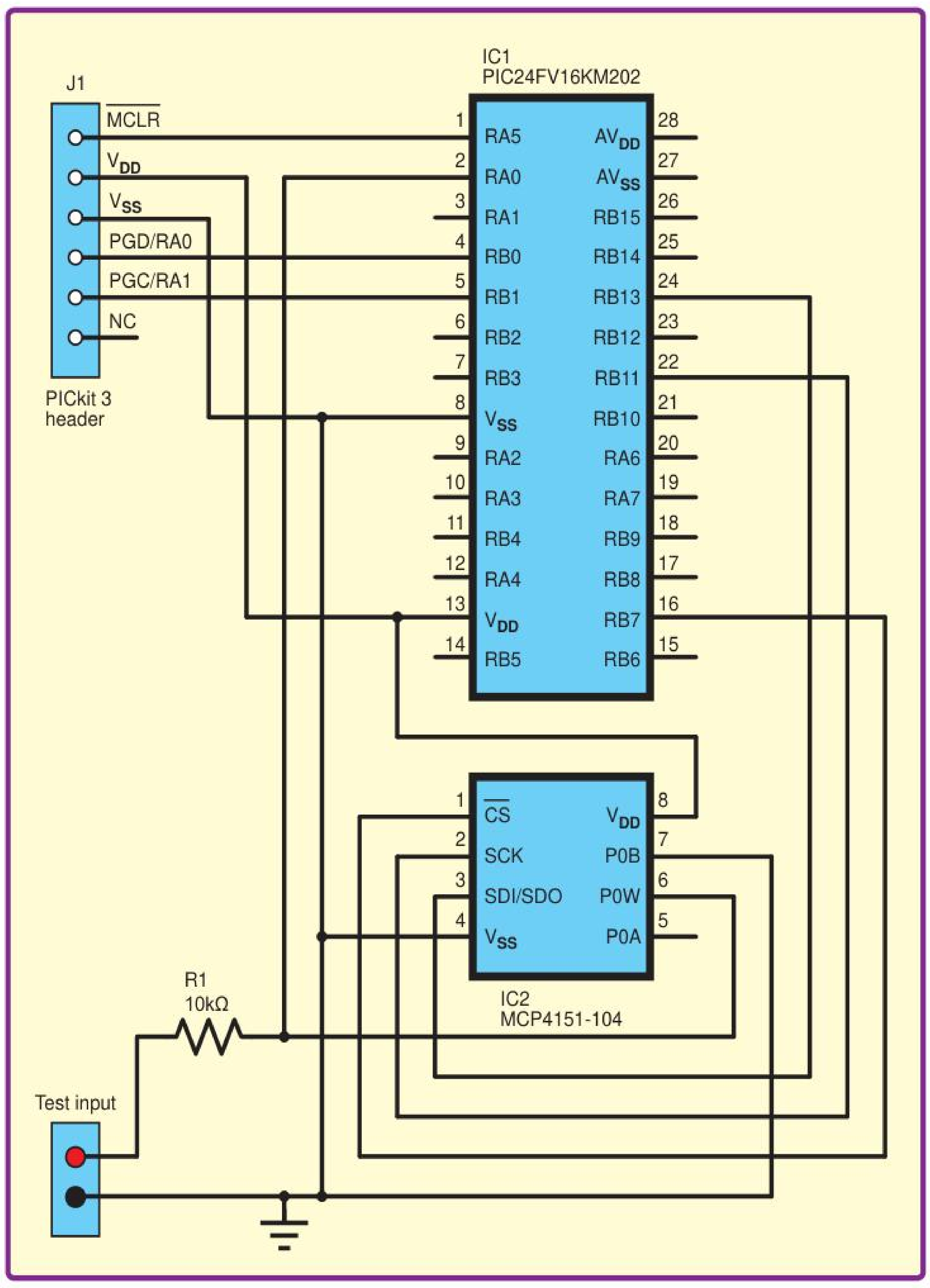
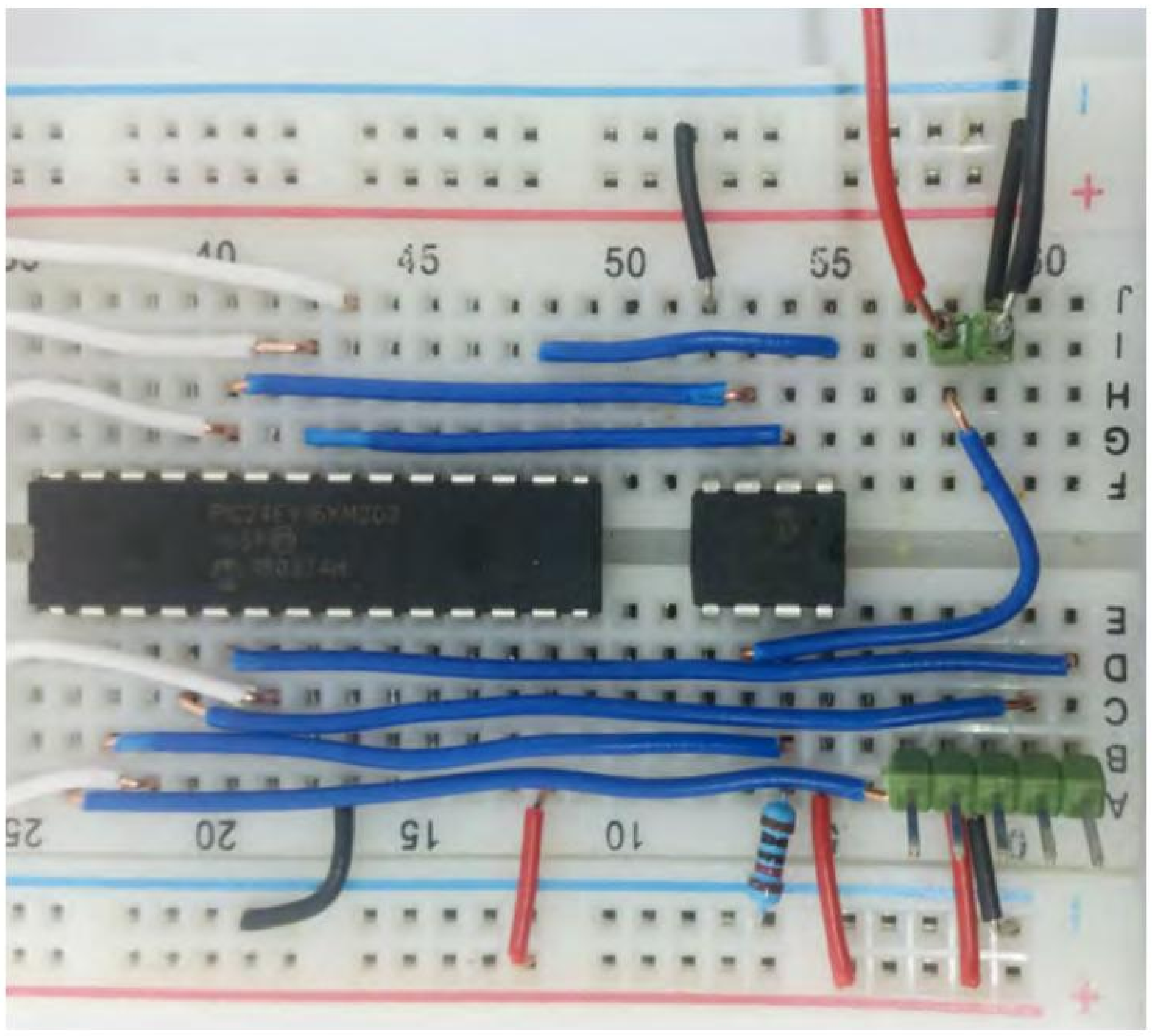

J1
MCLR
VDD
VSS
PGD/RA0
PGC/RA1
NC
PICkit 3 header
IC1
PIC24FV16KM202
RA5
RA0
RA1
RB0
RB1
RB2
RB3
VSS
RA2
RA3
RB4
RA4
VDD
RB5
AVDD
AVSS
RB15
RB14
RB13
RB12
RB11
RB10
RA6
RA7
RB9
RB8
RB7
RB6
1
2
3
4
5
6
7
8
9
10
11
12
13
14
28
27
26
25
24
23
22
21
20
19
18
17
16
15
CS
SCK
SDI/SDO
VSS
VDD
P0B
P0W
P0A
IC2
MCP4151-104
R1
10kΩ
Test input

Fig.4. PIC DC voltmeter schematic

Not all of Mike's technology tinkering and discussions make it to print.

You can follow the rest of it on Twitter at *@MikePOKeeffe*,

on the *EPE Chat Zone* or *EEWeb's* forums as *'mikepokeeffe'* and from his blog at *mikepokeeffe.blogspot.com*


40
45
50
55
60
J
I
H
G
F
E
D
C
B
A
25
20
15
10

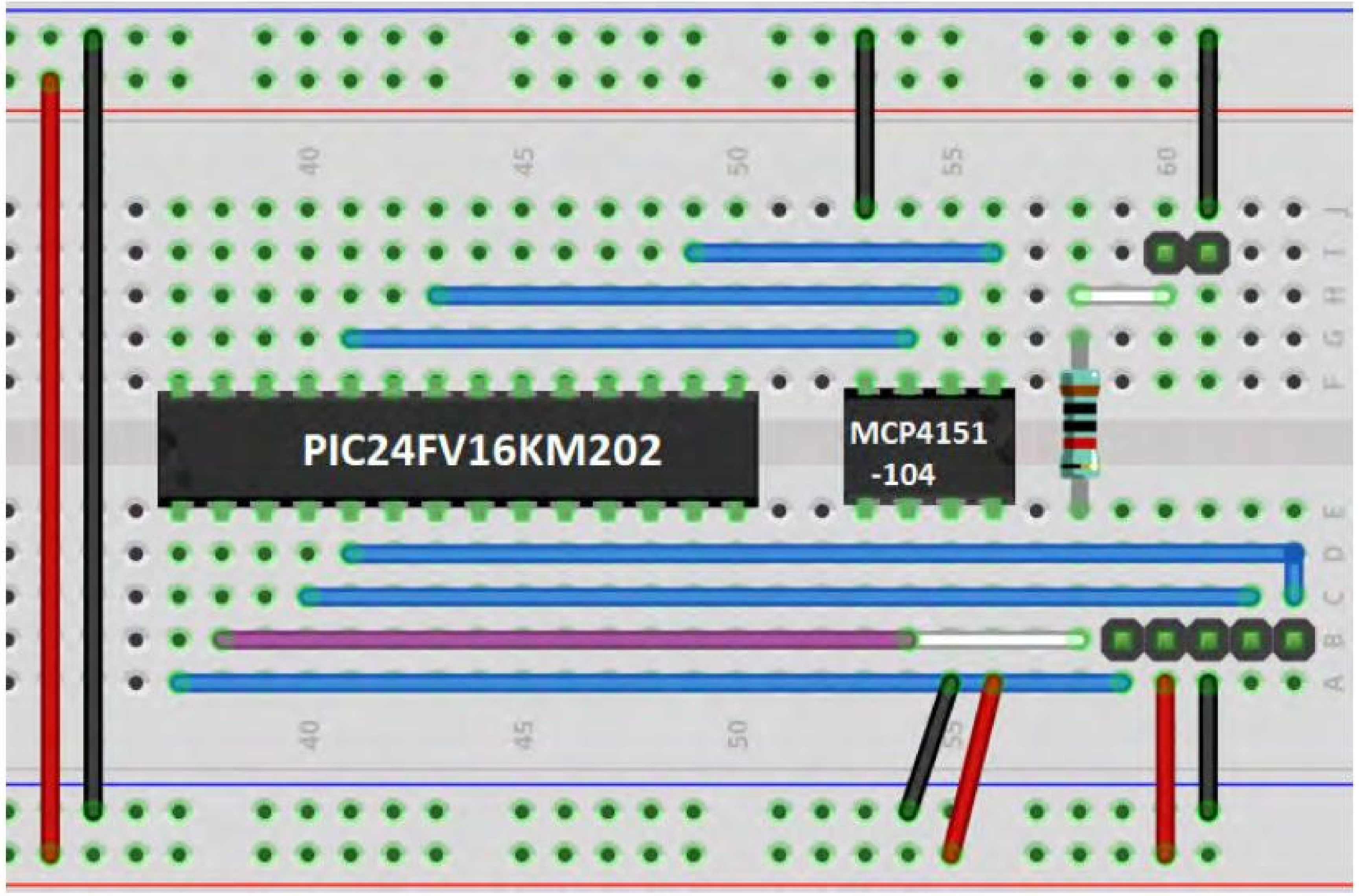

40
45
50
55
60
J
I
H
G
F
E
D
C
B
A
PIC24FV16KM202
MCP4151
-104

Fig.5. Breadboard layout for the PIC DC voltmeter – power is supplied to the 2-pin Molex connector. (The photo is an early version and slightly differs from the Fritzing diagram, but the functionality is the same.).

EXCLUSIVE OFFER

Microchip and EPE

have teamed up to bring you this AMAZING offer

USUAL PRICE
£42.64
(Inc VAT)
(model PG164140)

MPLAB PICkit 4
Microchip
Development tools

The MPLAB PICkit 4 In-Circuit Debugger/Programmer allows fast and easy debugging and programming of PIC and dsPIC Flash microcontrollers, using the powerful graphical user interface of MPLAB X Integrated Development Environment (IDE), version 4.15. The MPLAB PICkit 4 is connected to the design engineer's computer using a high-speed 2.0 USB interface and can be connected to the target via an 8-pin single in-line (SIL) connector. The connector uses two device I/O pins and the reset line to implement in-circuit debugging and In-Circuit Serial Programming (ICSP). An additional micro SD card slot and the ability to be self-powered from the target means you can take your code with you and program on the go.*

The MPLAB PICkit 4 programs faster than its predecessor, using a powerful 32-bit 300MHz SAME70 MCU, and comes ready to support PIC and dsPIC MCU devices. Along with a wider target voltage, the PICkit 4 supports advanced interfaces such as 4-wire JTAG and Serial Wire Debug with streaming Data Gateway, while being backward compatible for demo boards, headers and target systems using 2-wire JTAG and ICSP. The PICkit 4 also has a unique programmer-to-go function with the addition of a micro SD card slot to hold project code and the ability to be powered by the target board.

***Spend over £100 on any of EPE's products, including subscriptions, and receive a PICkit 4 worth* £42.64 for FREE**

This offer is available to UK & overseas customers; however, for orders in Europe & ROW the following amounts will be added to cover postage:
£4.05 Europe: £5.10 ROW

Hurry while stocks last!

(Please note: subscriptions purchased with this offer cannot be cancelled before they expire; also, goods purchased with this offer can only be returned for exchange)

OFFER ONLY VALID WHILE STOCKS LAST – DON'T MISS OUT!!
JUST CALL 01202 880299 OR VISIT OUR SECURE ONLINE SHOP AT: www.epemag.com

MICROCHIP

EPE EVERYDAY PRACTICAL ELECTRONICS

www.microchipDIRECT.com

CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Differentiator circuits

LAST MONTH, we addressed a question posted on the EEWeb forum by Michele Oliva about the circuit in Fig.1. The question concerned the interaction of the signals from two sources (V_1 and V_2), rather than the overall operation of the circuit. However, we noted in passing that the circuit was something like a 'summing differentiator', and that it was worth looking at op amp differentiator circuits in their own right, so that will be this month's topic.

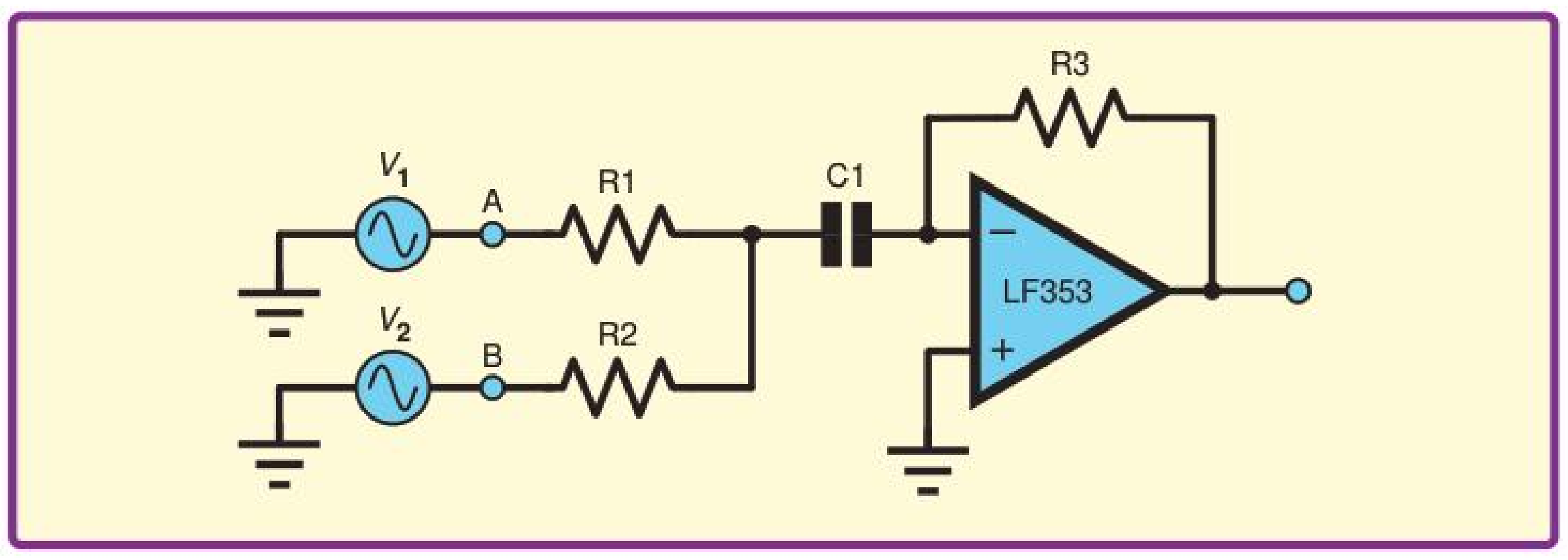


Fig.1. Michele Oliva's circuit from EEWeb Forum (with some edits to labelling)

We start with the basic ideal op amp differentiator (as shown Fig.2) and use it to introduce the basic principles and theory of operation of this circuit. Later, we will discuss the need for additional components (such as R_1 in Fig.1) for practical circuits.

The circuit in Fig.2 is called a 'differentiator', but what exactly do we mean by the term 'differentiator'? The answer is that this circuit performs the mathematical operation know as 'differentiation' – its output is proportional to the time derivative of the input signal. If you have studied (and can remember) calculus this may be a sufficient description, otherwise we need to answer the next question, 'what is a time derivative?'.

Derivatives

Derivatives in general are about rates of change of one quantity with respect to another, and time derivatives concern the rate of change of something with time. This is actually a concept we are accustomed to everyday life. We are familiar with speed, which is the rate of change of distance with time, and with acceleration, which is the rate of change of speed with time. The time derivative of distance is speed and the time derivative of speed is acceleration. Physicists and engineers use the terms 'velocity' and 'displacement' instead of 'speed' and 'distance' (to be specific about direction), but the basic idea is the same.

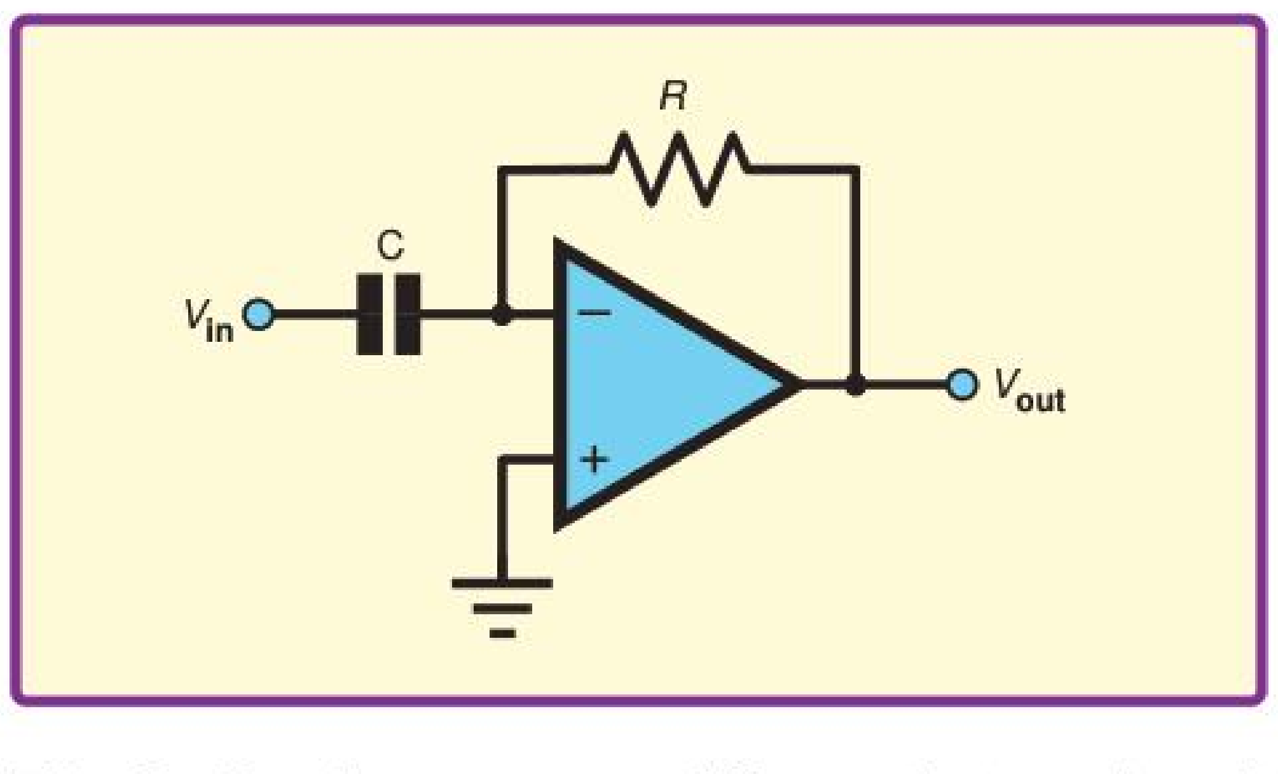


Fig.2. Basic op amp differentiator circuit

Having set the scene, we need to be a little more specific – a time derivative is the instantaneous rate of change, not the average change over a time period. As an example, consider speed again. If we measure distance travelled (x) over time (t) then the average speed for any portion of the journey/movement can be calculated using:

$$\text{Average Speed} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

Where x_1 is the total distance travelled at time t_1 and x_2 is the total distance travelled at some later time t_2. The symbol Δ (upper-case Greek letter delta) is used in mathematics to represent 'change of', so Δt means change of time – that is ($t_2 - t_1$) in our example.

We can measure an average speed over any length of time Δt that we choose (within the overall duration of the journey/movement of interest). Consider reducing the time interval. If we make Δt sufficiently small then it approaches zero time – it becomes infinitely small (or 'infinitesimal'). Under such conditions, we use the symbol d instead of Δ and the value we get by dividing dx by dt is the instantaneous speed, or the time differential of x

$$\text{Instantaneous Speed} = \frac{dx}{dt}$$

Writing the time differential of x in the form dx/dt is referred to as Leibniz's notation (there are other ways of notating differentials). A modern pure mathematician may point out that the definition of differentials, as just presented, which follows the foundations of the idea from Leibniz and others in the 17th century is not very rigorous, however, it sufficient for our purposes.

The reverse of differentiation is integration. So if we integrate speed with time we get distance and if integrate acceleration with time we get speed. We are looking at the op amp differentiator circuit in this article, but there is also an op amp integrator circuit. In general, integrator circuits are more widely used than differentiators and they form the basics of many filter designs (we will look at the filter characteristics of differentiators later).

History

These mathematical circuits are an important part of the origin and history of op amps. The name 'operational amplifier' reflects the original use of these circuits – performing mathematical operations in analogue computers. The first op amps were built using vacuum tube technology, date from the late 1940s and were based on development work performed during the 1940s for the United States National Defense Research Council. GA Philbrick of George A Philbrick Researches Inc. (GAP/R) and CA Lovell of Bell Labs are both credited with designing the first op amps around 1948. Although analogue computers predated op amps, op amps facilitated the design and construction of better and more practical analogue computers.

Op amps can be used to build circuits that perform mathematical operations such as addition, scaling, integration and differentiation. By wiring these operational units together it is possible to create circuits which represent (and hence solve) the mathematics of a complex problem, such as might be encountered in the design of an aircraft. The early analogue computers that used vacuum tube op amps were used mainly for military design work. They were enormous (tens of cubic meters) and consumed vast amounts of power (tens of kilowatts). Over the years the primary use of op amps has changed from analogue computing to signal processing (amplification, level shifting, mixing and filtering etc). However, analogue computing has not entirely gone away – for example, one can occasionally come across digitally-controlled analogue-computer-like circuits lurking inside modern integrated circuits.

Applications

Differentiator circuits can be used in applications other than analogue computers. A typical example would be measuring the rate of change of some quantity in a process or machine. This value might be used to trigger an alarm if something is changing too quickly. More generally, differentiators can be used to detect any fast-changing events on their inputs (such as square wave edges) in order to trigger a circuit to do something in response. Differentiators modify waveform shapes (eg, converting a triangle wave to a square wave) so can be used in applications that manipulate wave shapes, such as musical effects. A widely used control systems technique is called 'Proportional, Integral, Differential control', or PID for short. As the name, implies this requires differentiation, so a PID controller may employ an op amp differentiator if implemented as an analogue circuit (however, many such controllers are of course digital these days).

Theory

Returning to the theory behind the differentiator, so far we have used speed as an example for introducing differentiation, because it is such a familiar everyday concept. In electronics, there are a number of important time-derivative relationships. For example, power is the time derivative of energy and current is the time derivative of charge; and the latter is of particular importance to our differentiator circuit.

Electric current is the flow of electric change. Current (in amps) is defined as the instantaneous rate of flow of charge (in coulombs per second). That is, current (I) is the amount of charge (Q) flowing through a wire or component per second at a given instance. So we can write current as the time differential of charge:

$$I = \frac{dQ}{dt}$$

If the charge flows into a capacitor then the capacitor will store and accumulate that charge (or discharge if the current is flowing out from the capacitor).

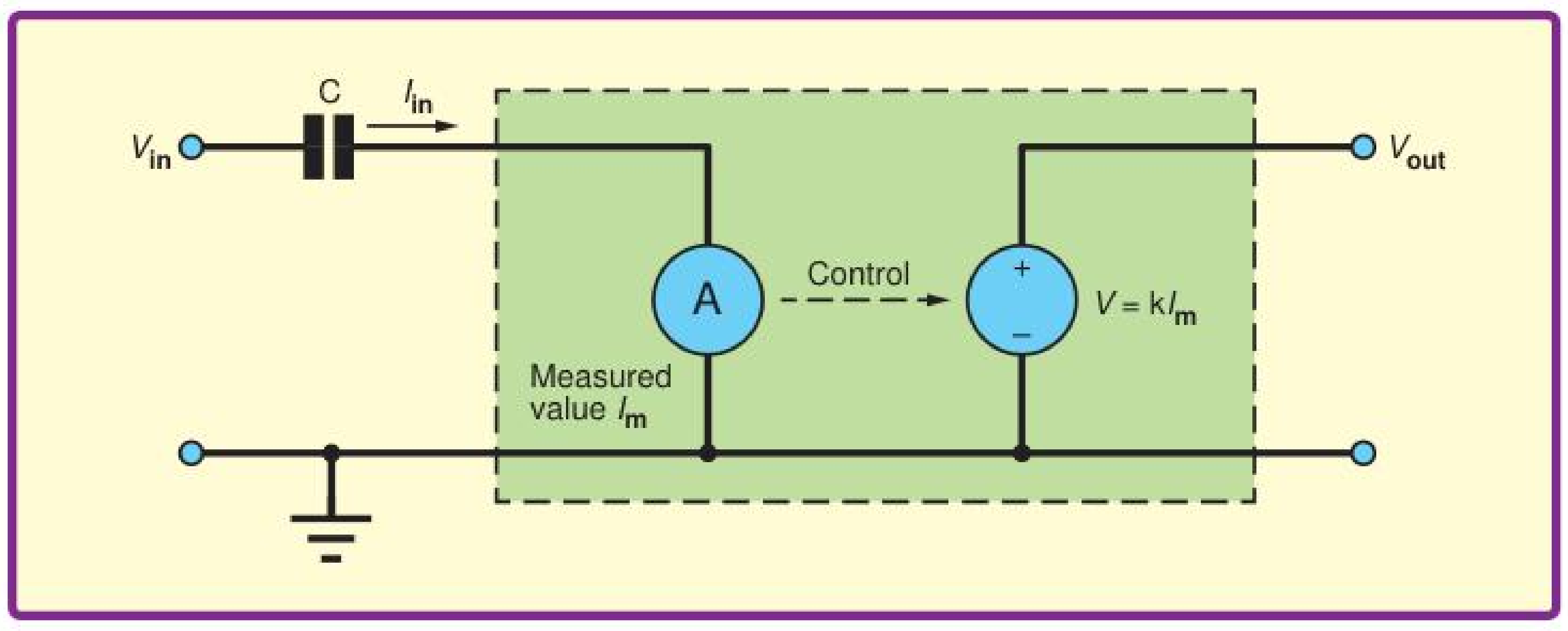


Fig.3. Differentiator concept circuit

The voltage across a capacitor is proportional to the charge stored, with the specific voltage depending on the capacitance. Capacitance (C) (in farads) is defined by the ratio of charge Q (in coulombs), held by the capacitor to the voltage across the capacitor, V (in volts), that is:

$$C = \frac{Q}{V}$$

Rearranging we can write $Q = CV$. We can substitute this into our time differential definition for above, giving:

$$I = C\frac{dV}{dt}$$

Note that we write the C outside the differential because C is constant – it does *not* change with time. If the voltage is increasing then dV/dt will be positive, indicating a charging current flowing into the capacitor. If the voltage is decreasing then dV/dt will be negative, indicating a discharge current flowing out of the capacitor. If the voltage is not changing then dV/dt will be zero – no current is flowing in or out of the capacitor. The above equation is called the 'characteristic equation' for the capacitor. It is the fundamental relationship between current through and voltage across a capacitor, in the same way that Ohm's law ($I = V/R$) provides the characteristic equation of an ideal resistor of resistance R.

The characteristic equation for the capacitor shows us the current through a capacitor is proportional to the time derivative of the voltage across it, which is why there is a capacitor at the input of the differentiator circuit in Fig.2.

Circuit concept

Using the capacitor equation we can devise a conceptual circuit for producing an output voltage that is proportional to the rate of change (time differential) of the input voltage. Such a circuit is shown in Fig.3. The input voltage (V_{in}) is connected directly across a (grounded) capacitor so the current in the capacitor will be given by the above equation – that is, it will be proportional to the rate of change of V_{in}. We measure the current through the capacitor as I_m and use the measured current to control a voltage source so that its output is directly proportional to the measured current ($V = kI_m$). Assuming that the current measurement is perfect ($I_m = I_{in}$), and voltage control is also perfect ($V_{out} = kI_m$), then the output will be given by giving:

$$V_{out} = kI_m = kI_{in} = kC\frac{dV_{in}}{dt}$$

For a current measurement to be perfect the voltage dropped across the ammeter must be zero. In practice, this is not possible, but an op amp current measurement circuit can get close, at least over a limited range of relatively small currents, by using a virtual earth as the current input. We discussed virtual earths last month, but will recap briefly here. For a circuit such as that in Fig.2, where the op amp is used with negative feedback, and the non-inverting input is grounded, the inverting input behaves as if it is connected to ground. This is because the op amp is acting as a feedback control circuit trying to keep the voltage across its inputs at zero. If the non-inverting input is at zero (because it is grounded) then this control of the voltage difference will ensure the inverting input is always at zero too. For a real op amp this process will not be perfect, but with a high performance, very high open-loop gain op amp it can be a very good approximation.

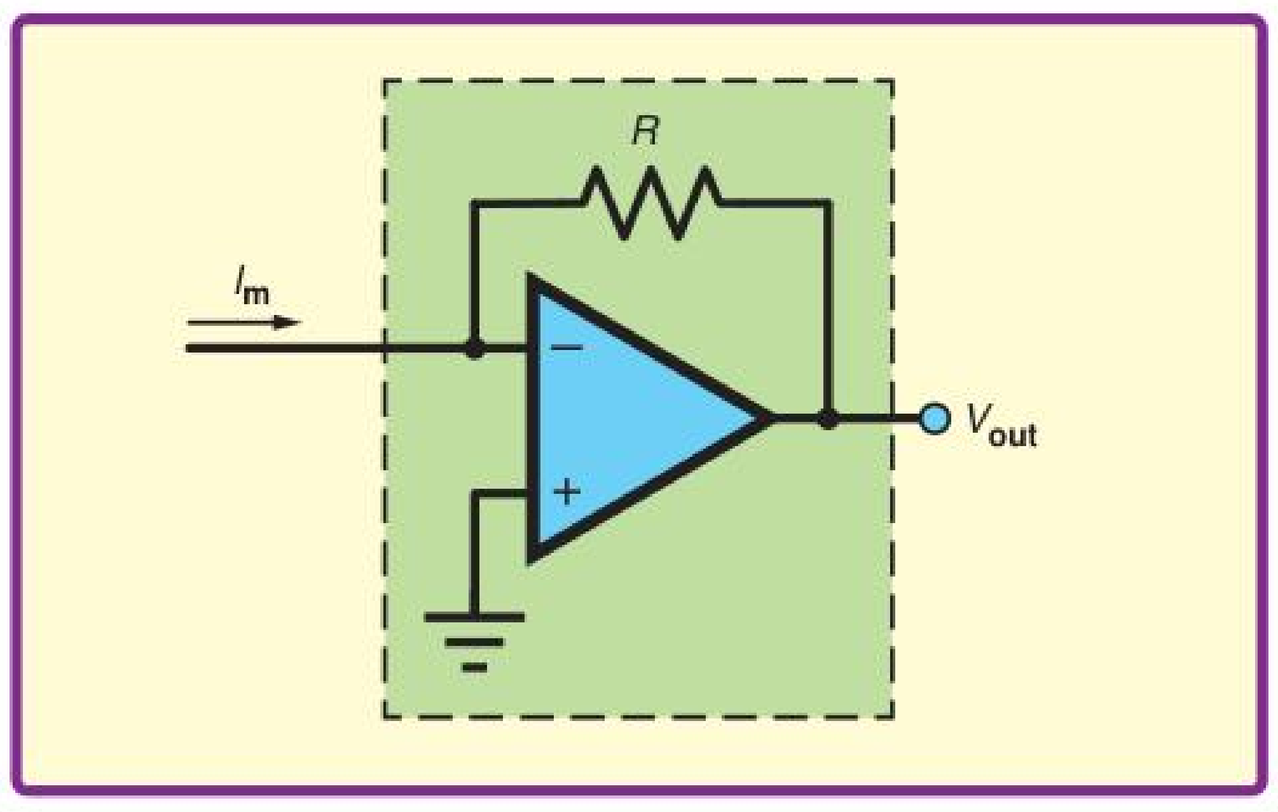


Fig.4. Op amp transimpedance amplifier circuit

Transimpedance amplifier

The circuit in Fig.4 is an op amp transimpedance amplifier. It has an input of current and an output of voltage, so the gain V_{out}/I_m has units of ohms (compare $I = V/R$ in Ohm's law). This circuit could also be called a 'transresistance amplifier', but the term 'transimpedance' is more general and more commonly used. The term 'transimpedance' is short for 'transfer impedance' – with 'transfer' indicating an input to output relationship, rather than the direct voltage-across to current-through relationship of a basic impedance or resistor. The transimpedance amplifier is exactly what we need to implement the measure-current and control-voltage part of the concept circuit in Fig.3.

To analyse the circuit in Fig.4, first note that the input is connected directly to the virtual earth. With an ideal op amp the input would be exactly like a ground connection – that is, there is zero input impedance and the input current simply behaves as if it is flowing to ground. However, the input is not really directly connected to ground – so where does the input current actually go? There are two possibilities – through the resistor (R) or into the op amp.

The amount of current flowing into the op amp depends on its input impedance and its input bias current. For an ideal op amp, the input bias current is zero and the input impedance is infinite. Therefore, no current flows into the op amp in the ideal version of this circuit, which means all of the input current must flow through *R*. This makes it easy to find the voltage dropped across *R* – it is simply $I_m R$ by Ohm's law. We also know from our previous discussion of virtual earth that the input end of the resistor is at 0V (ground), so the other end must be at $-I_m R$ volts. So we have, for Fig.4:

$$V_{out} = -RI_m$$

Real op amps are available with very high input impedances and very low input bias currents. Some op amps are specifically designed for use in transimpedance configurations and may be suited to use in differentiators.

Differentiator circuit

Looking at our differentiator concept circuit in Fig.3 we see that the measure-current-to-control-voltage section can be implemented using a transimpedance amplifier – the shaded block in Fig.3 corresponds with Fig.4. The value of *k* from Fig.3 for the transimpedance amplifier is –*R*. The combined schematic is exactly that shown in Fig.2.

For the circuit in Fig.2 the input current to the transimpedance amplifier is the capacitor current. Applying the previous calculations for Fig.3, but with $V_{out} = -RI_m$ rather than $V_{out} = kI_m$ we get an equation for the output of the op amp differentiator:

$$V_{out} = -RC\frac{dV_{in}}{dt}$$

Frequency response

It is instructive to look at the frequency response of a differentiator circuit, which we can do using LTSpice simulation. The circuit in Fig.5 is a semi-ideal differentiator (the op amp has extremely high gain and gain-bandwidth product). A differentiator is a form of high-pass filter, with a frequency response as shown in Fig.6. The key thing to note is that the gain simply goes on increasing as frequency increases. In this example the gain reaches about 95dB at 10MHz (approximately 56,000).

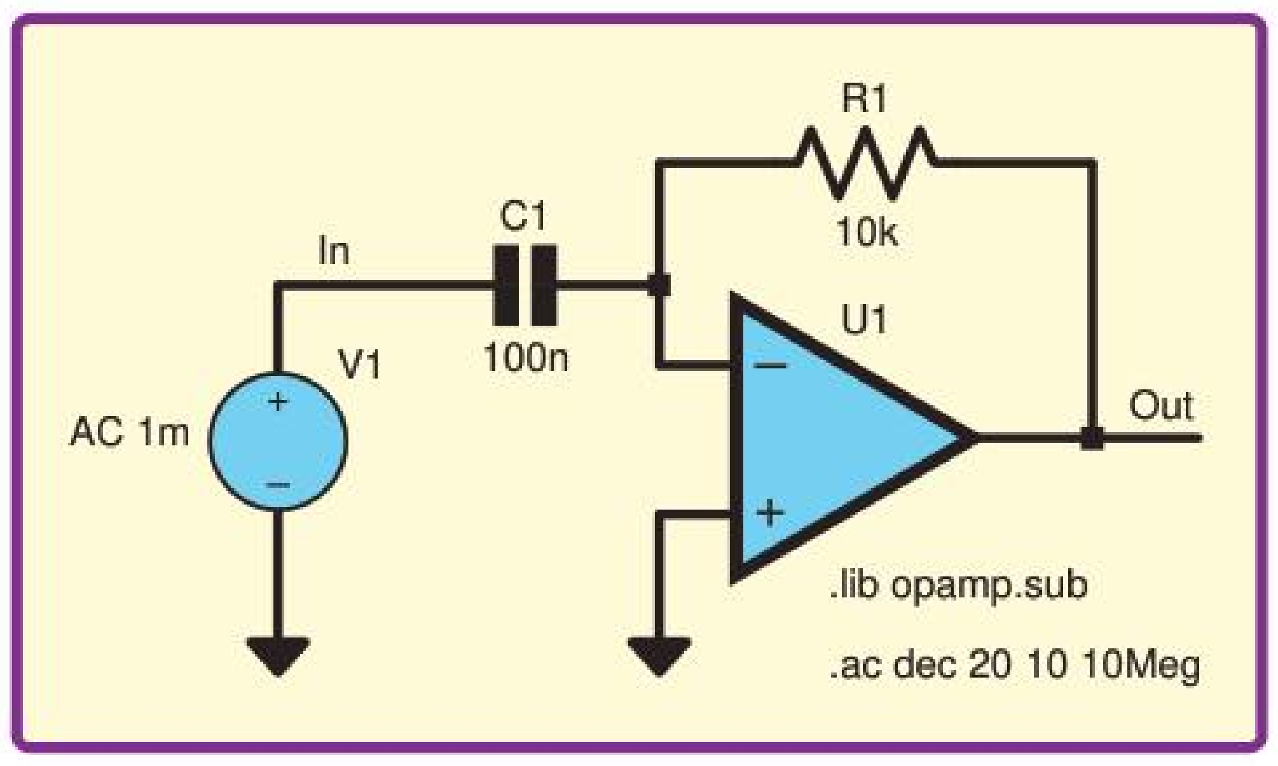


Fig.5. Basic differentiator circuit simulation schematic (for frequency response)

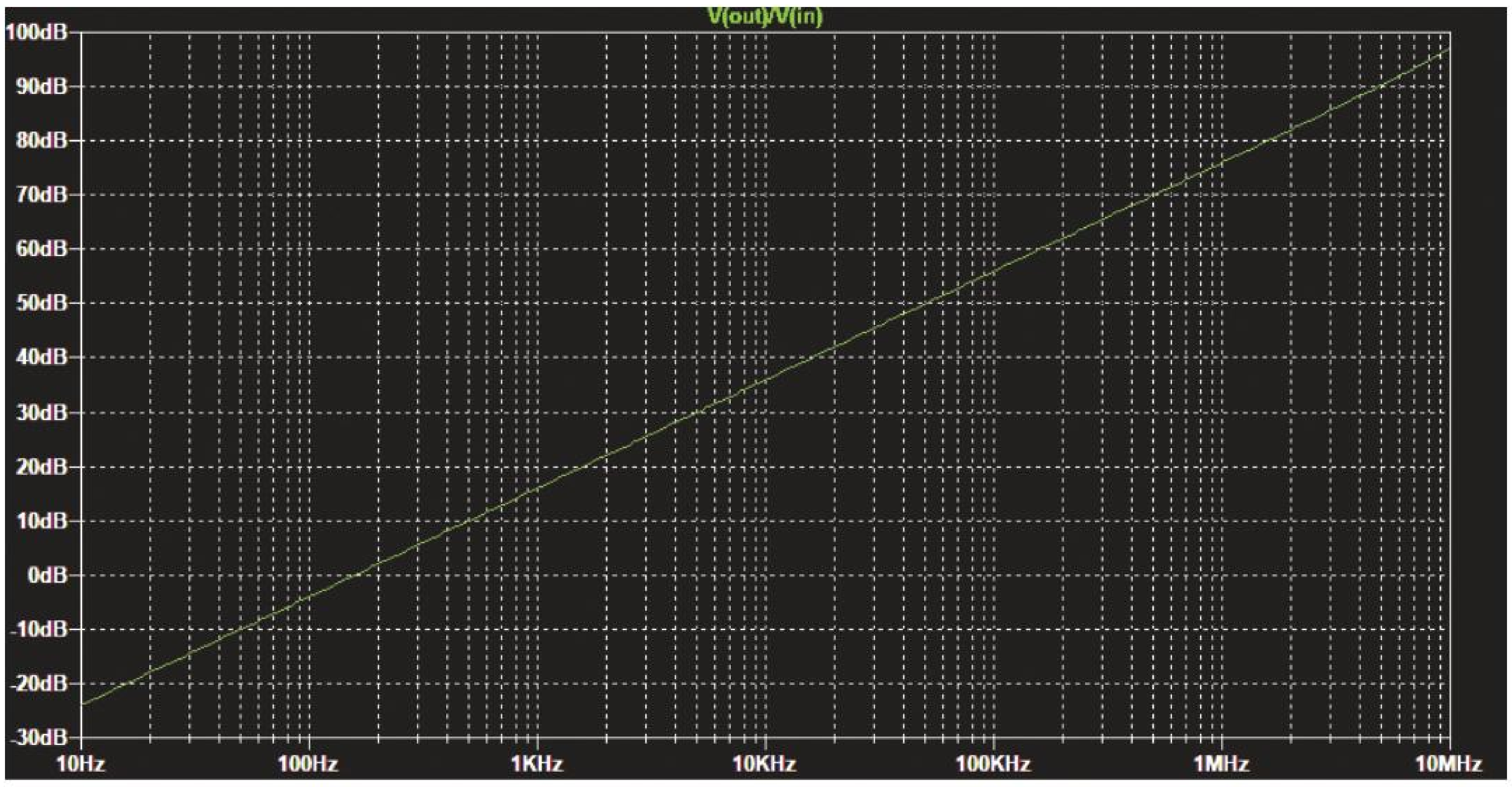


Fig.6. Frequency response simulation results for the circuit in Fig.5

This steady increase in gain makes sense – the differentiator output is proportional to rate of change of input, and for a sinewave of a fixed amplitude, the rate of change (of the fastest part of the waveform) will increase as frequency increases, so the output level of an ideal differentiator will increase with frequency. The frequency at which the gain of an differentiator is 1 (0dB) is given by $1/2\pi R_1 C_1$ which is 1/(2×π×10kΩ×100nF) = 159Hz for the circuit in Fig.5.

Problems

The very high gain of differentiators at high frequencies poses potentially severe problems for real implementations. There are a couple of issues. First, the high gain at high frequencies can lead to instability – the circuit may oscillate permanently, or fast input changes may trigger temporary oscillations. The second problem is due to random noise, which is inevitably present on any real input signal. Even if the noise has a low amplitude it is likely to contain relatively high frequency content (compared with the wanted signal). These high frequency components of the noise cause small but rapid changes in the input voltage, for which the differentiator will produce a relatively large output response. Thus, differentiator circuits can be very sensitive to noisy inputs.

The problems with noise and instability can be overcome by reducing the differentiator's gain at high frequencies. This can be achieved by inserting a resistor in series with the input capacitor, or by connecting a capacitor in parallel with the feedback resistor. Either of these will have the effect of levelling off the gain at a frequency given by $1/2\pi RC$, where are *R* and *C* refer to the values of the relevant series or parallel pair. Adding both components will result in a frequency response that levels off at the lower of the two $1/2\pi RC$ frequencies and then starts decreasing from the higher.

An example of adding both the capacitor and resistor (to the circuit in Fig.5) is shown in Fig.7. The simulated frequency response is shown in Fig.8. For this example, $1/2\pi R_2 C_1$ is about 32kHz (1/(2×π×50Ω×100nF)) and $1/2\pi R_1 C_2$ is about 640kHz (1/(2×π×10kΩ×25pF)). These frequencies match the turning points on the frequency response curve in Fig.8. Between these frequencies the gain flattens at a magnitude given by R_1/R_2, which in this case is 10000/50 = 200 = 46dB (the dB value is calculated using $20\times\log_{10}(200)$). Again, this can be seen in Fig.8 – the flat section of the response is at a gain of around 46dB.

The flat gain is equal to the gain of an inverting op amp amplifier formed if both capacitors are removed from the circuit (C_1 shorted, C_2 open circuit). If the two frequencies set by the *RC* combinations are close together, the frequency response may not fully flatten off, and will peak at a value below R_1/R_2.

With the additional components limiting the high-frequency gain of the circuit in Fig.7, it will only act as a differentiator with respect to signals at frequencies below the point at which the curve flattens. To put it another way, very fast changing inputs will not be correctly differentiated. This is what we want if we need to prevent noise from producing unwanted output.

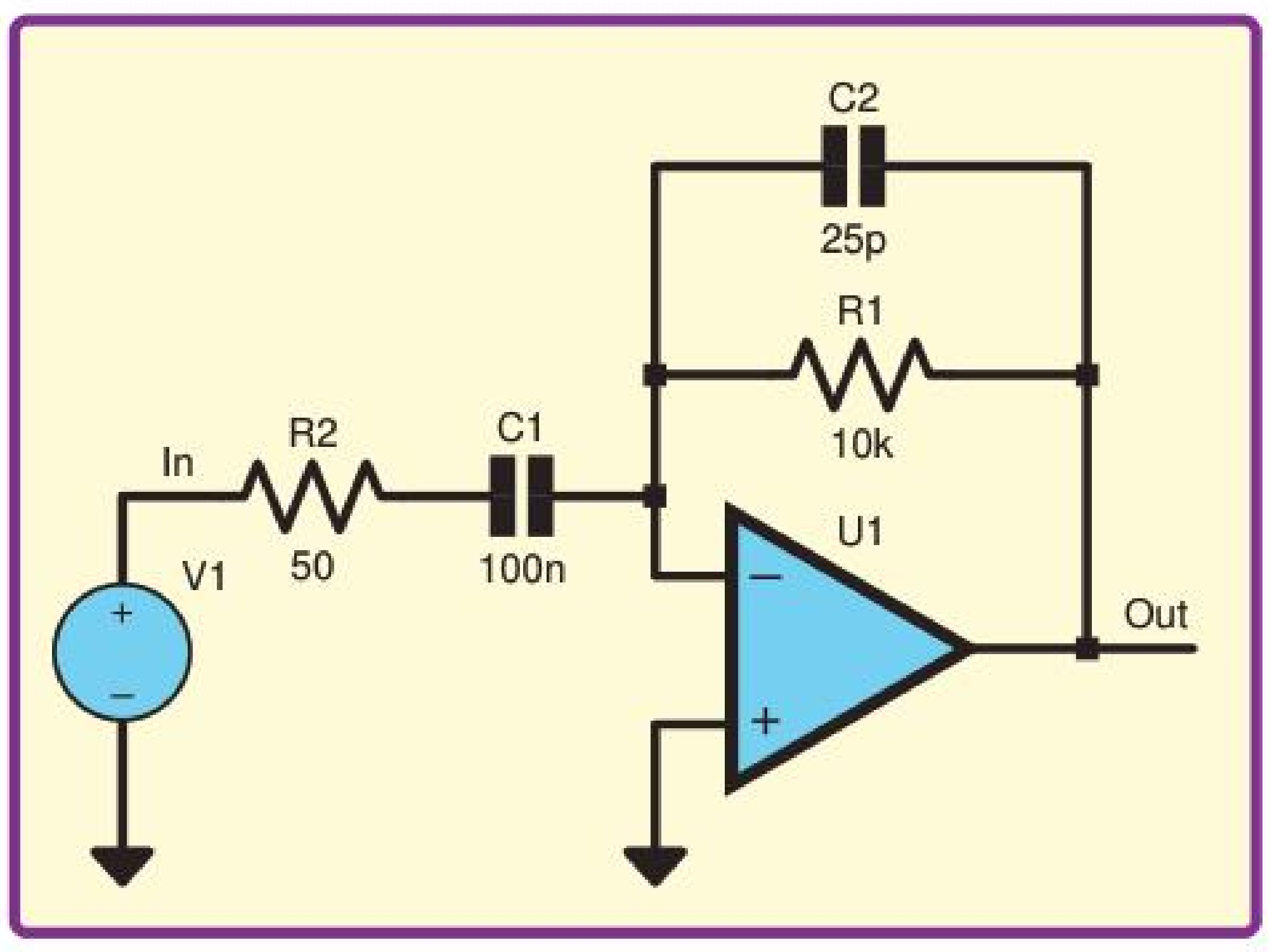


Fig.7. Differentiator with components added for improved stability and reduced sensitivity to noise.

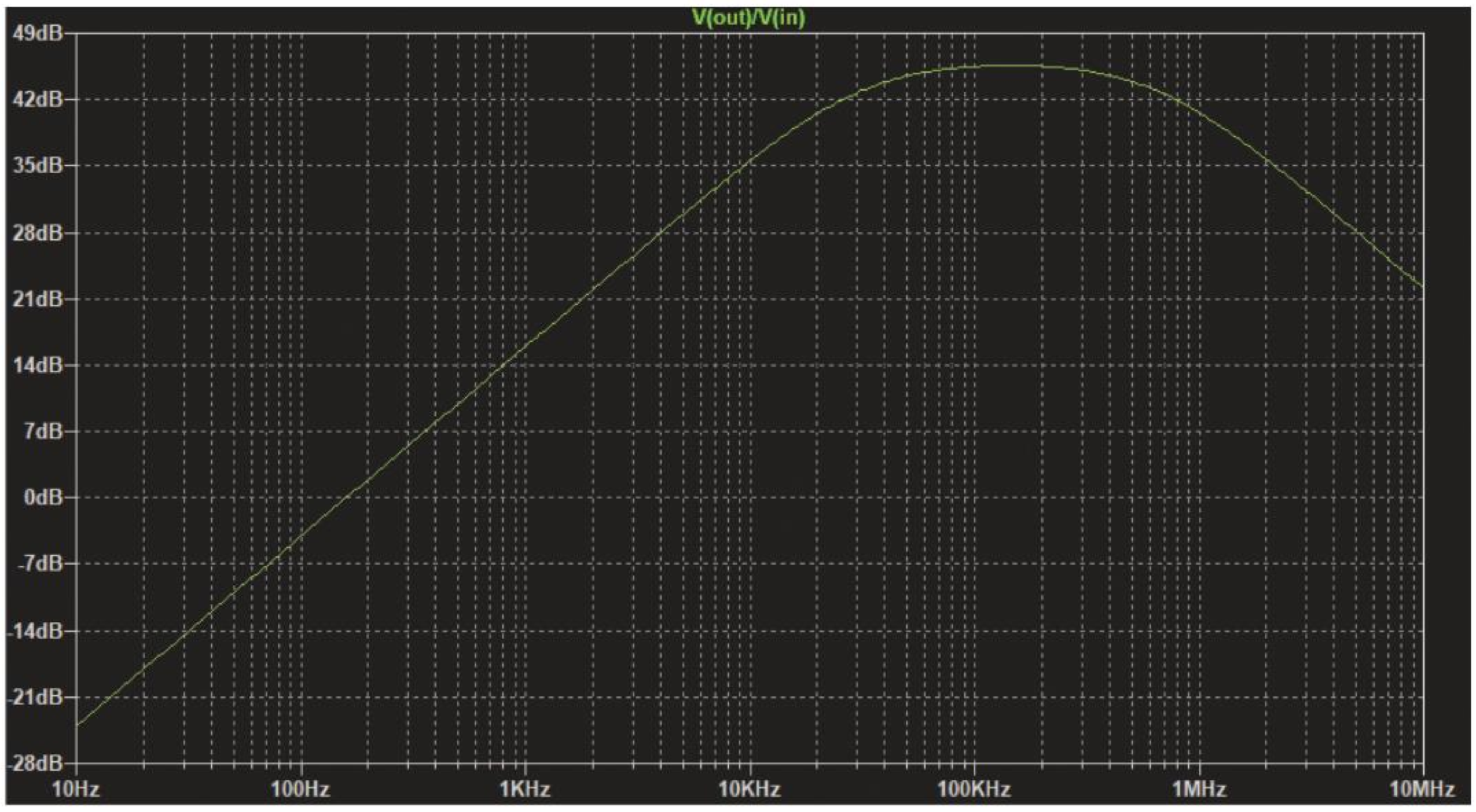


Fig.8. Frequency response simulation results for the circuit in Fig.7

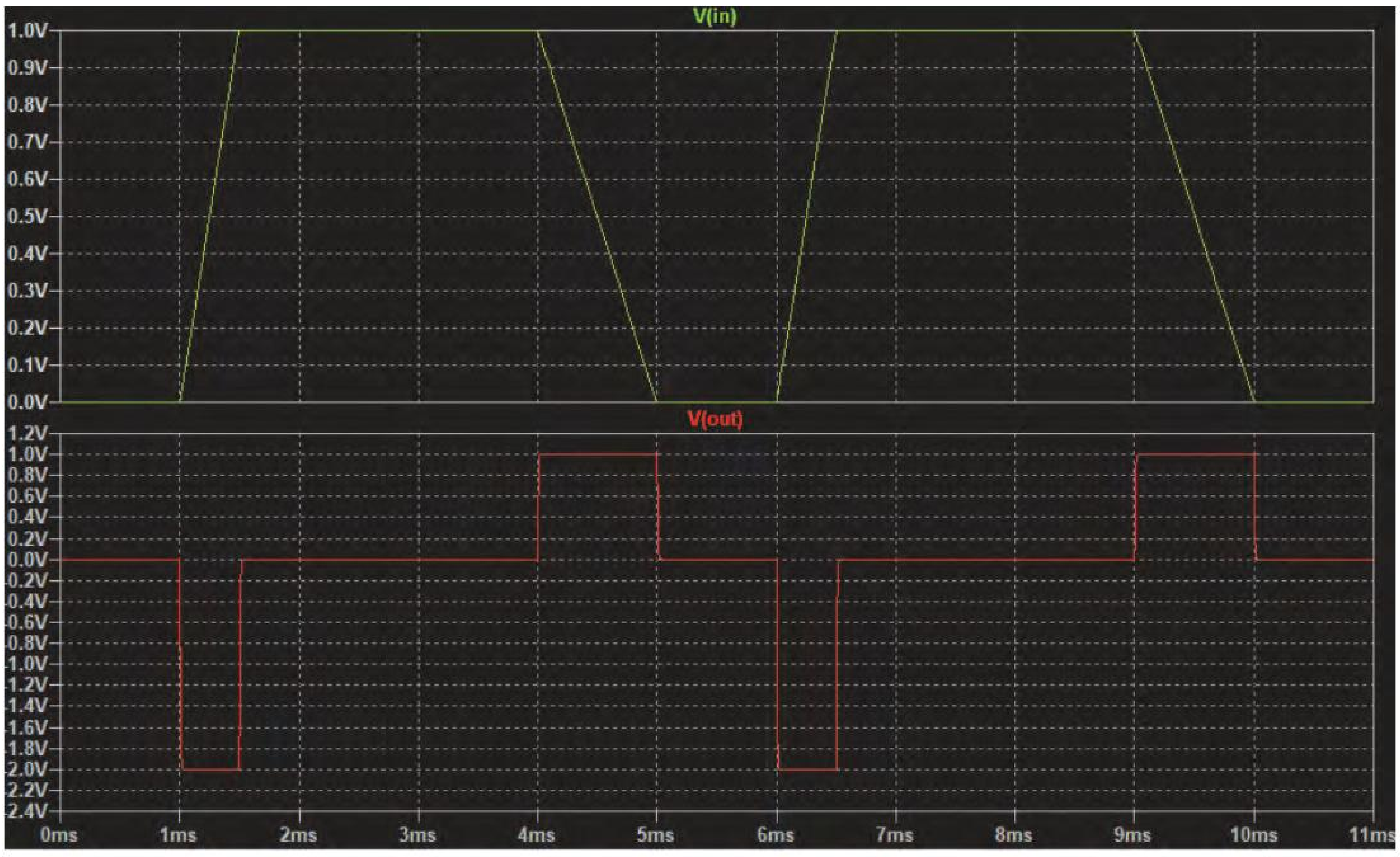


Fig.9. Simulated differentiator input and output waveforms (for the circuit in Fig.7)

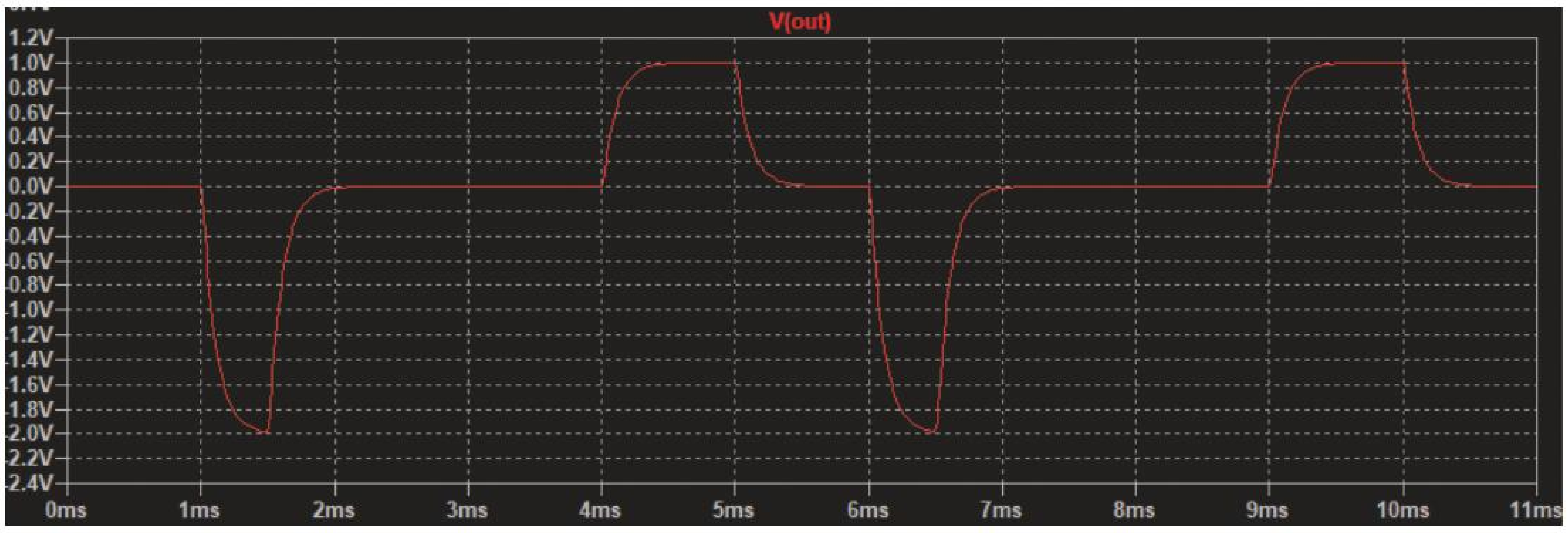


Fig.10. Simulated output from the circuit in Fig.7, with the same input as Fig.9, but with R2 = 1kΩ and C2 = 1nF

The component values should be selected in accordance with the signals expected in the application for which a differentiator is being used.

Differentiator circuit operation

To see the differentiator operating we can run a transient simulation with a suitable input signal. An example result, using the circuit in Fig.7, is shown in Fig.9. The input is a positive-going pulse wave of amplitude 1.0V, with a cycle time of 6ms (about 167Hz pulse repetition frequency). The rising edge takes 0.5ms, but the falling edge is slower, taking 1.0ms. Both edges are linear ramps, so the time differential is constant during these transitions and can be calculated by dividing the voltage change by the edge duration. Thus the rates of change of the input edges shown in Fig.8 are 1.0/0.0005 = 2000V/s and –1.0/0.001 = –1000V/s respectively.

Applying the equation for the op amp differentiator to the circuit in Fig.7 we get:

$$V_{out} = -RC\frac{dV_{in}}{dt}$$

$$= -10\times10^{3}\times100\times10^{-9}\times\frac{dV_{in}}{dt} =$$

$$-0.001\frac{dV_{in}}{dt}$$

From this we would expect an input signal increasing at 2000V/s to produce an output voltage of –0.001 × 2000 = –2V. For an input decreasing at 1000V/s (rate of –1000V/s) we get an output of –0.001 × (–1000) = 1V. From the lower waveform in Fig.9 we see that this is very close to the simulated result.

The rate of change of the input signal in Fig.9 changes instantaneously (for example, from zero to 2000V/s as the rising edge starts). In an analogy with speed, this is a bit like having infinite acceleration. However, real input signals are likely to be 'rounded at the edges', to an extent dependent on the nature of the signal source. Similarly, for rapid changes in input rate a differentiator's output must change very rapidly. However, real op amps are limited in the maximum rate of change of their output, which will limit the edge speeds of their outputs.

The shape of the output waveform is also affected by the addition of the high-frequency gain limiting components. These also tend to limit the rate of change of the output signal. If the time constants for these *RC* pairs are not correctly set then the output produced may deviate from an accurate representation of the time derivative of the input. For example, the output may look like a spike when it should be a square pulse, as in Fig.9. An example of this is shown in Fig.10. This is the same simulation as shown in Fig.9 except the values of R_2 and C_2 have been changed to 1kΩ and 1nF respectively. The lower pulse only just gets to the –2V value, which should be produced throughout the positive input edge. An inaccurate output such as this may be acceptable if the purpose of the circuit is simply to detect fast input changes, rather than accurately measure the input time differential.

Simulation files

The LTSpice files discussed in this month's *Circuit Surgery* are available for download from the *EPE* website.

AUDIO OUT

By Jake Rothman

Analogue synthesis – Part 2

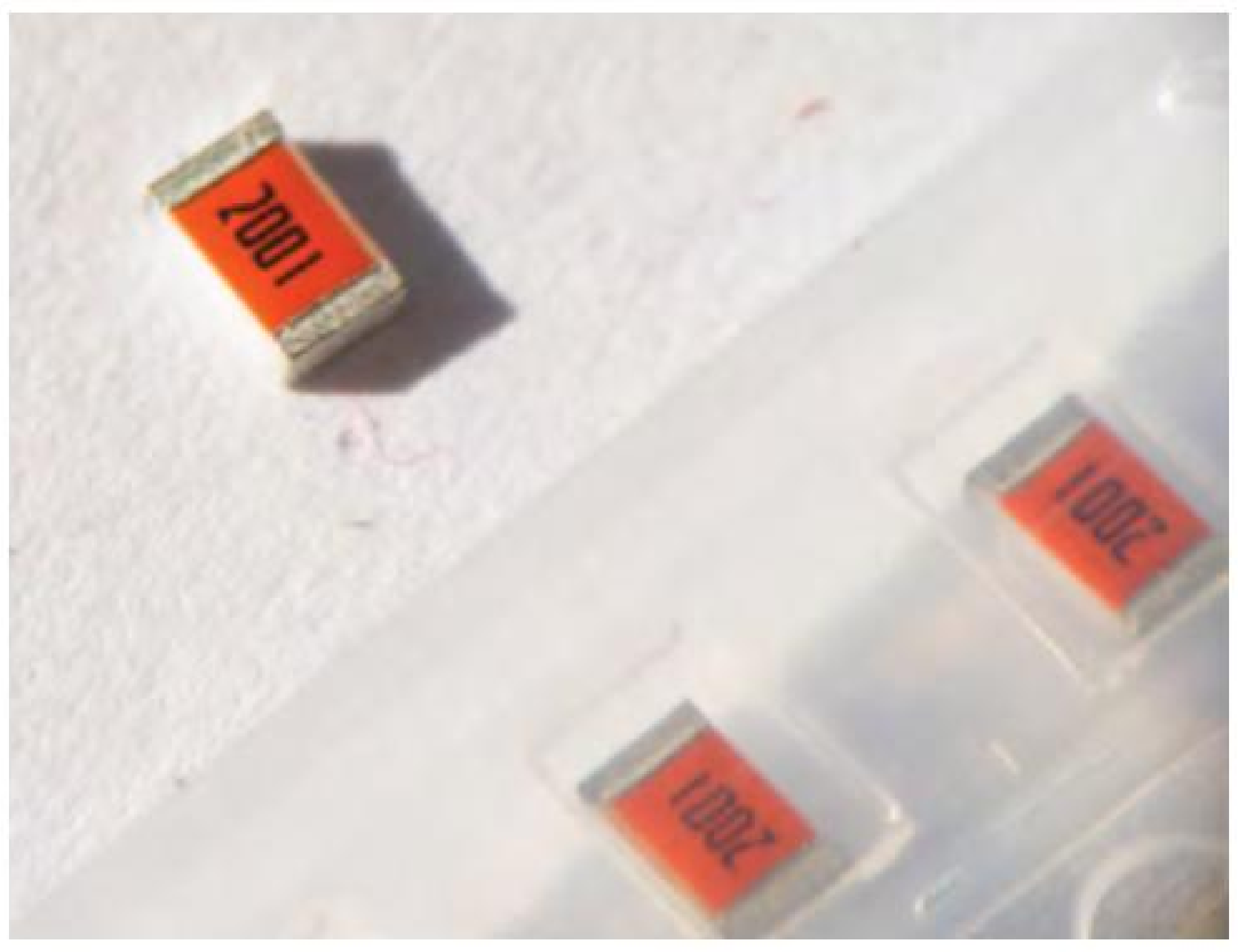


Fig.29. A positive temperature coefficient (PTC) resistor part number LT7339002A2K-0JTE. Unusually for a surface mount part it has a distinctive colour, but marked with the standard resistor code 2001.

Final oscillations

In *Part 1*, I covered voltage-controlled oscillators (VCOs) and mentioned that stability could be improved with a special positive temperature coefficient resistor. The Tel Labs Q81 which had the required +3300 parts per million/°C temperature coefficient (0.33%/°C) was often specified in the 1980s, but is now rare and expensive. Often, I source substitutes for long-lost analogue parts lurking among low-cost surface mount components. Mouser UK (**mouser.co.uk**, obviously) is usually the best place to look, and I found a 2kΩ 3900ppm/°C resistor by TE Connectivity for 77p, as shown in Fig.29. (A 44p leaded 1kΩ resistor is also shown in Fig.30). By combining this with a 300Ω normal metal-film resistor we will get the right temp co, as shown in Fig.31. This is near enough to replace the 2.2kΩ lower arm resistor (R11) of the control voltage potential divider in the VCO. I put the temperature-compensation resistor on the same surface-mount adapter board as the dual transistor – see Fig.32. Surprisingly, when I tested the oscillator in hot sunlight I found the stability worse with the resistor. Maybe the compensation was excessive.

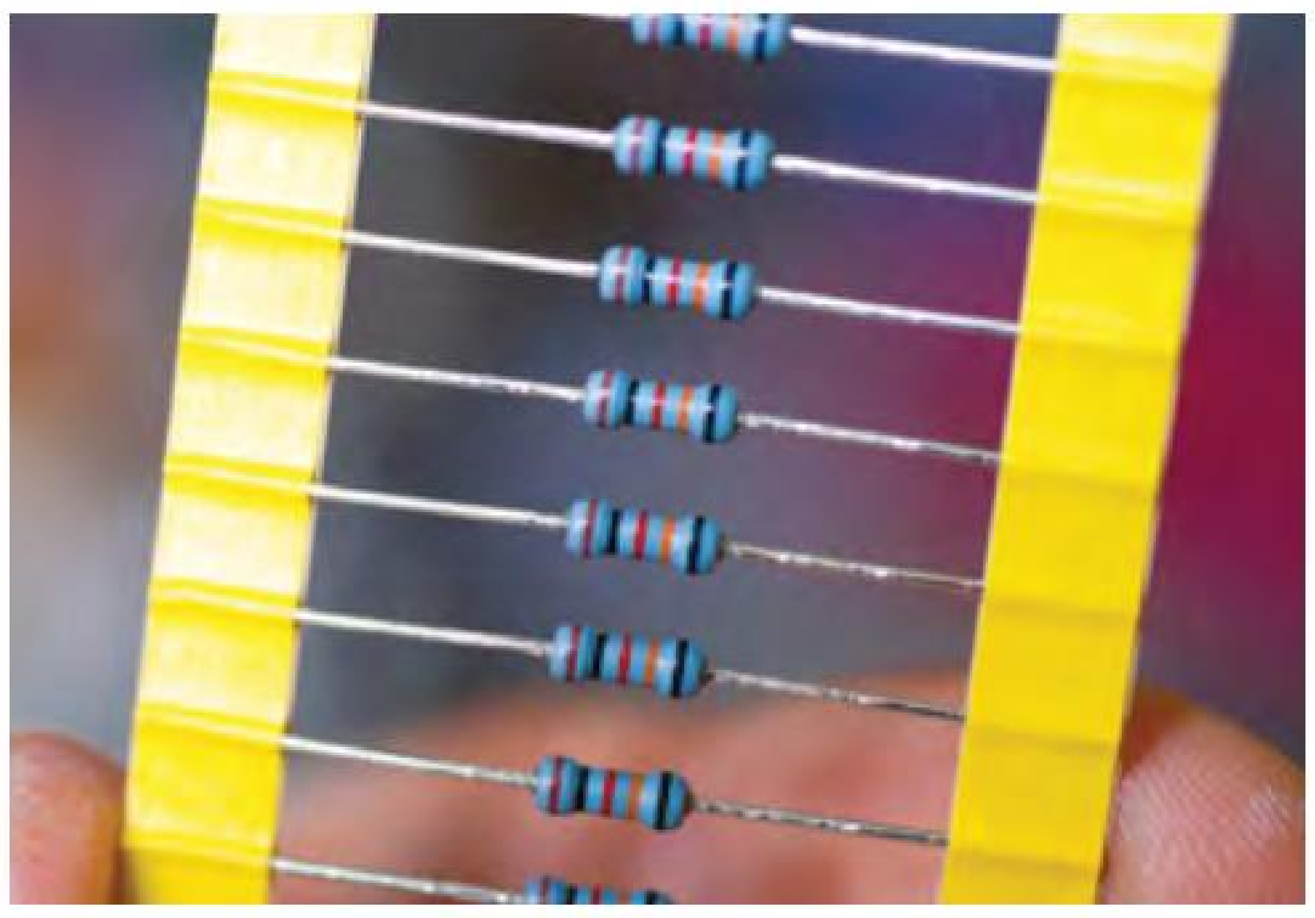


Fig.30. This PTC resistor is 1kΩ +3000ppm/°C part No. LT300014T261K0J. The colour code is a bit odd. According to the TE Connectivity data sheet, the orange and black bands represent the temperature coefficient, aka 'temp co'.

Other VCO designs may benefit from this resistor technique; for example, Ray Wilson's MFOS VCO from Soundtronics. Balancing badly defined variables in non-linear analogue circuits takes time, which is why in mass production they have been replaced by digital technology. However, digital simulation of tactile instant analogue response generally fails to deliver, which is why we will be tweaking with solder and component value changes for the foreseeable future. The circuits here are for experimentation, and have not been 'productionised'; that said, their low-power requirements are unique and good for education. Fig.33 shows a Veroboard version of the exponential VCO from Fig.21 in last month's *Part 1*. I'm not going to give layouts, since the ones shown here are really just working, rough first drafts where I build straight from the circuit diagram – and I am quite sure you are capable of doing the same!

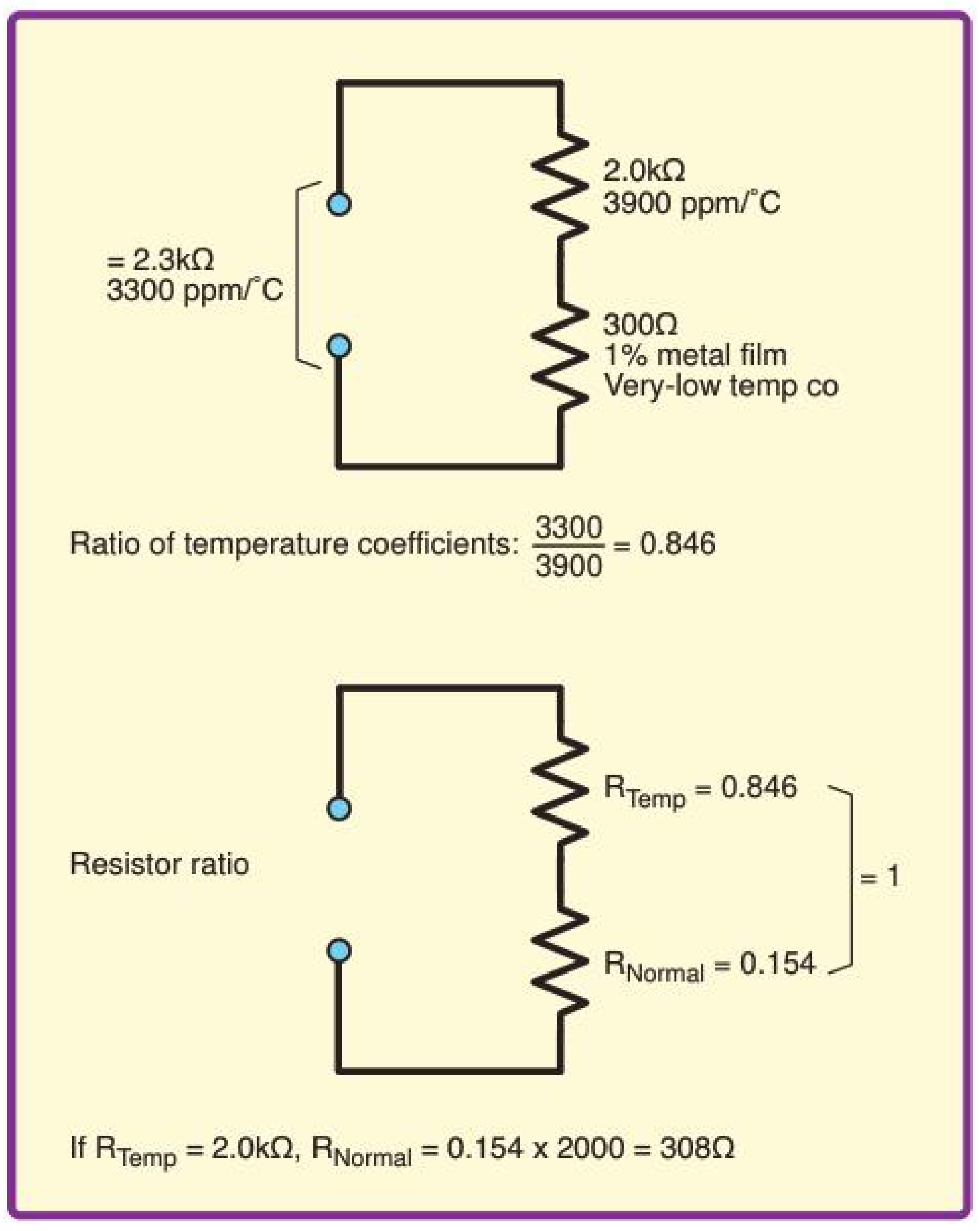


Fig.31. It is possible to get the required value and temp coefficient by combining resistors – a good task for spreadsheet fans!

Gate generators

Nobody likes to listen to a continuous tone from an oscillator, apart from the odd minimalist Scandinavian composer, so we have to manipulate tones to make them sound musically interesting. Obviously, the first requirement is to be able to turn it on and off. In simple instruments, this is normally done with the stylus making contact with the keys; for example, the low-power 'Stylophone' or the keyboard note switch. Once a voltage-controlled oscillator (VCO) is used, it generally runs continuously and has to be muted when no note is played. To do this, the output of the oscillator must be 'gated' and for this to take place a gate signal has to be generated (see Fig.42). The gate signal is also used to trigger an envelope, a time-varying voltage that controls the volume and also modulates filters and effects.

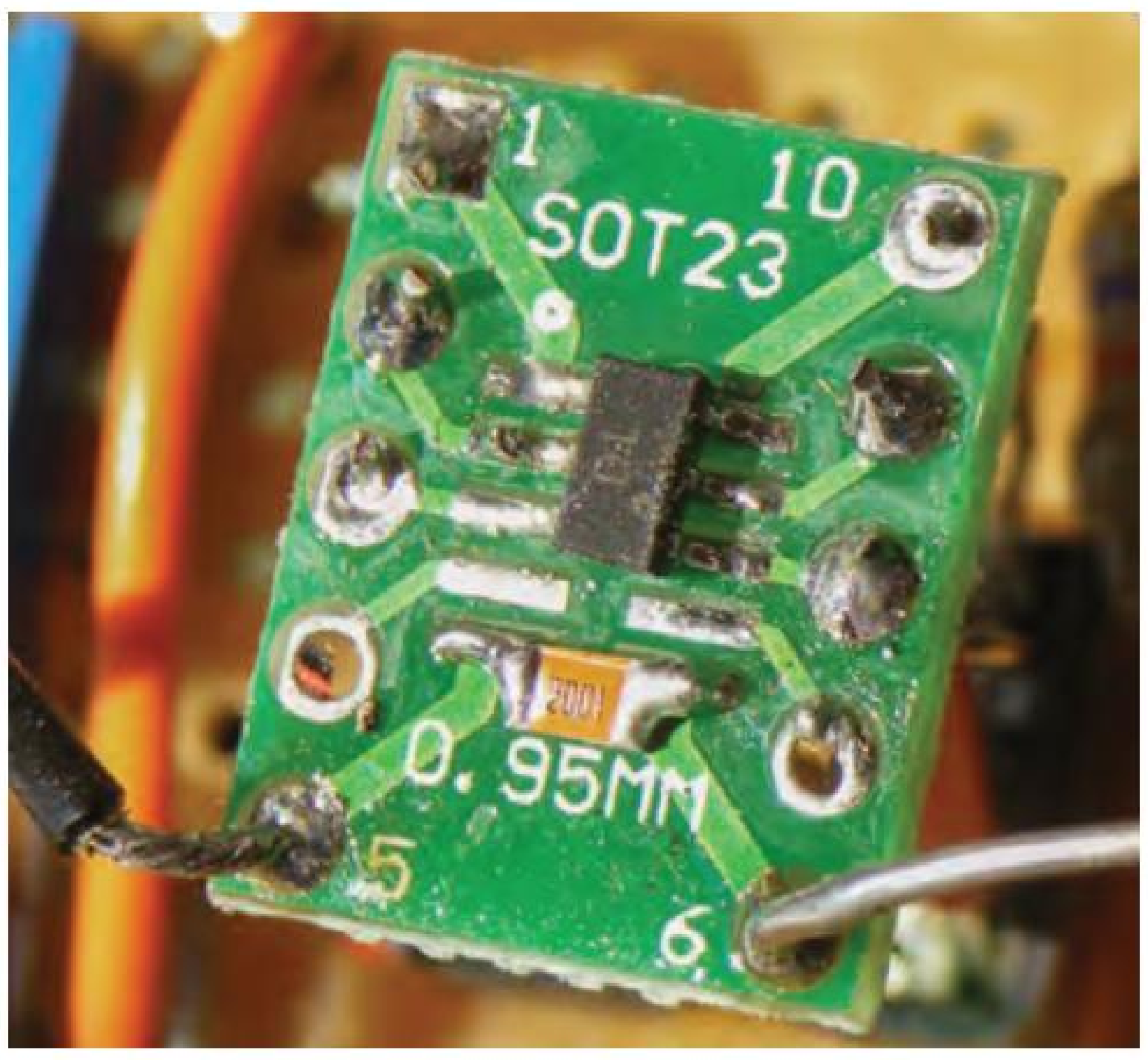


Fig.32. SMT resistor mounted with dual transistor to get best temperature stability. Mounting the assembly on a heatsink to get extra thermal mass would improve things. SMT components are tiny and hence very sensitive to draughts.

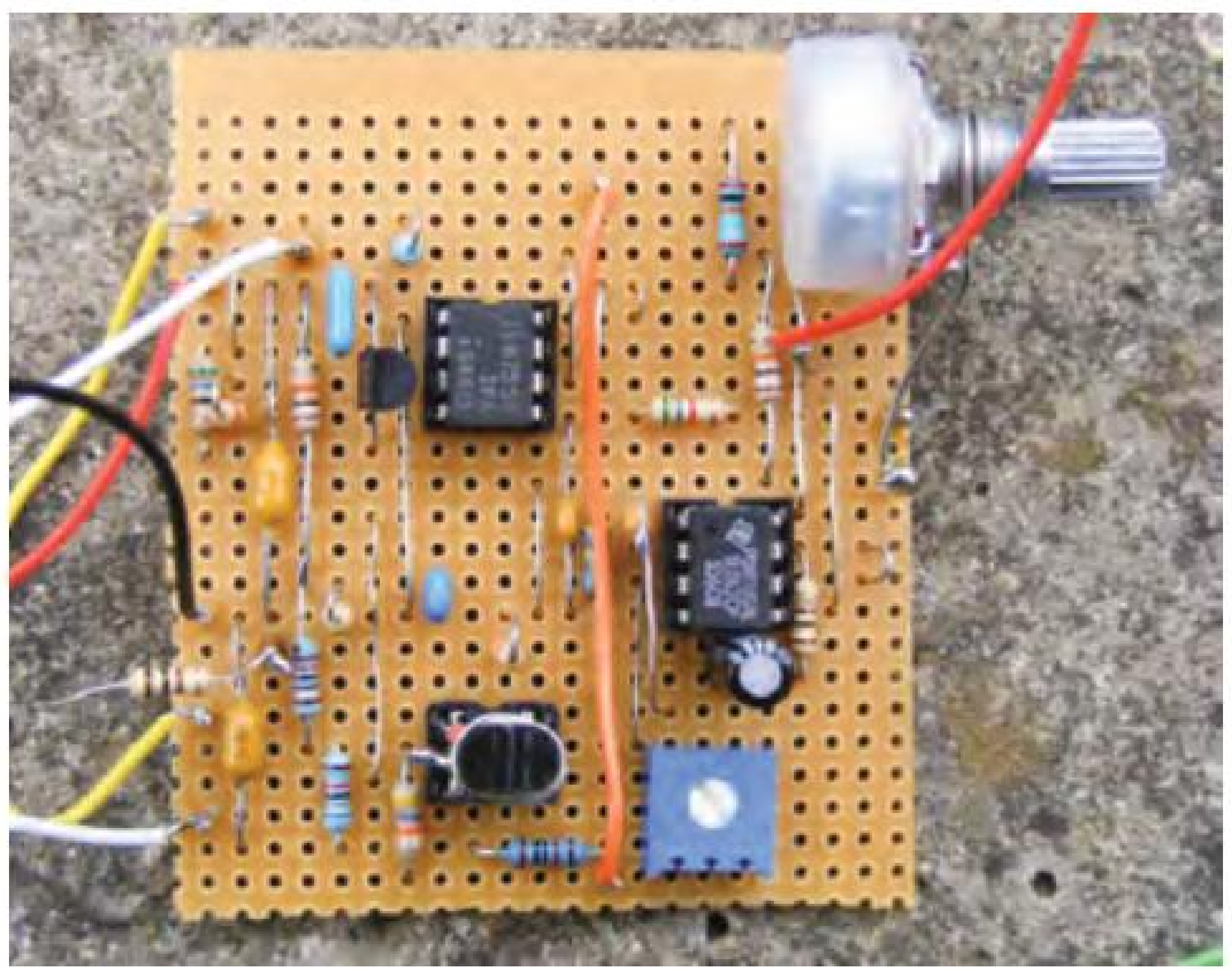


Fig.33. The VCO from last month's circuit (Fig.21) built on Veroboard. This still has discrete transistors, but a later version had the SMT assembly of Fig.32 plugged in. I was disappointed to find little improvement – further research is needed.

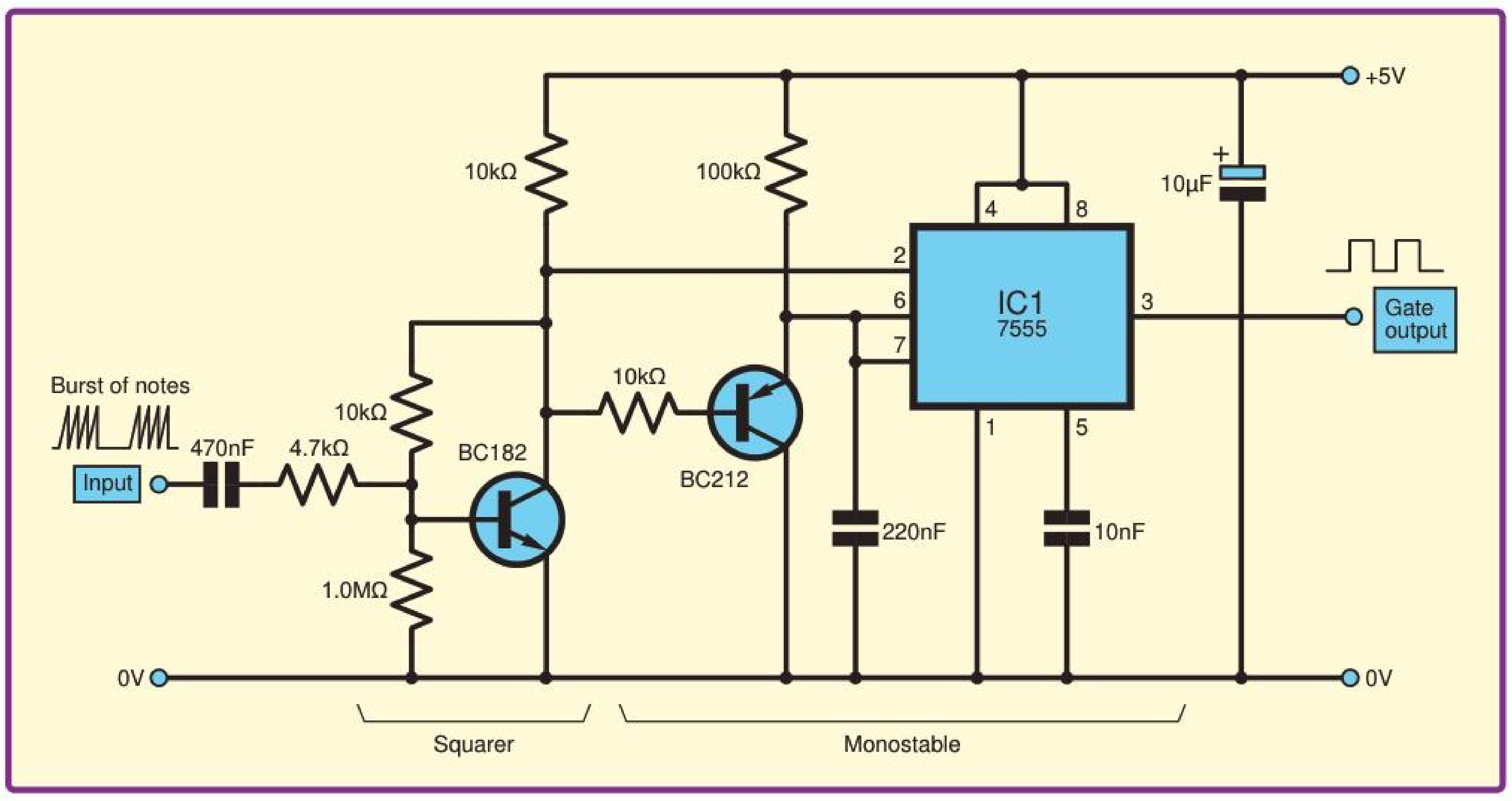


Fig.34. A monostable built around a 7555 IC can generate a gate from a note being played.

Switches

A very popular synthesiser kit in the early 1980s was the Tim Orr designed *Transcendent 2000*. This simply used extra gate switch contacts on the keyboard. I remember having to align these with the pitch contacts so they came together at the right time – a right pain – but it could provide a high current. Today, switch contacts are expensive and electronic components are cheap, so most designs use a single-contact keyboard with circuitry to generate the gate signal from the note signal.

Monostables

Even if the oscillator is 'self-gating', such as in the Stylophone circuit, where the oscillator only operates when the stylus is touched on the keys, it is still useful to have a gate output. In the GenX-1 there was a bias voltage of 2.5V on the keyboard contacts and this was used to generate a gate with a trigger circuit. This controlled the filter and muted the oscillator. In the *Low-Power 'Stylophone'*, a gate cannot be generated from the keyboard since there is insufficient voltage on the lowest notes. A solution is to use a monostable, which is a circuit where the output 'hangs-on' for a set time period after being triggered by the first cycle of the note waveform. The time period of the monostable has to be long enough that it does not retrigger on the lowest notes. This technique can also be used with the 7555 ramp oscillator. A suitable circuit using the 7555 is shown in Fig.34.

VCO gating

The exponential 7555 circuit, like most VCOs never stops oscillating. Even if no note is played it will carry on at a very low frequency. This could cause problems with breakthrough in the gaps between notes, and in this case we need to add an oscillator mute which can be controlled by a gate signal.

In this circuit, muting occurs if the timing capacitor (C3) is pulled to the positive rail. This can be achieved by wiring a PNP transistor across it to act as a shorting switch, as shown in Fig.35. To turn the transistor on and allow muting, its base must be pulled low. Normally, gate signals are a few volts positive to turn on and 0V for off, and we can achieve this with a couple of extra transistors – TR3 and TR4 in Fig.38.

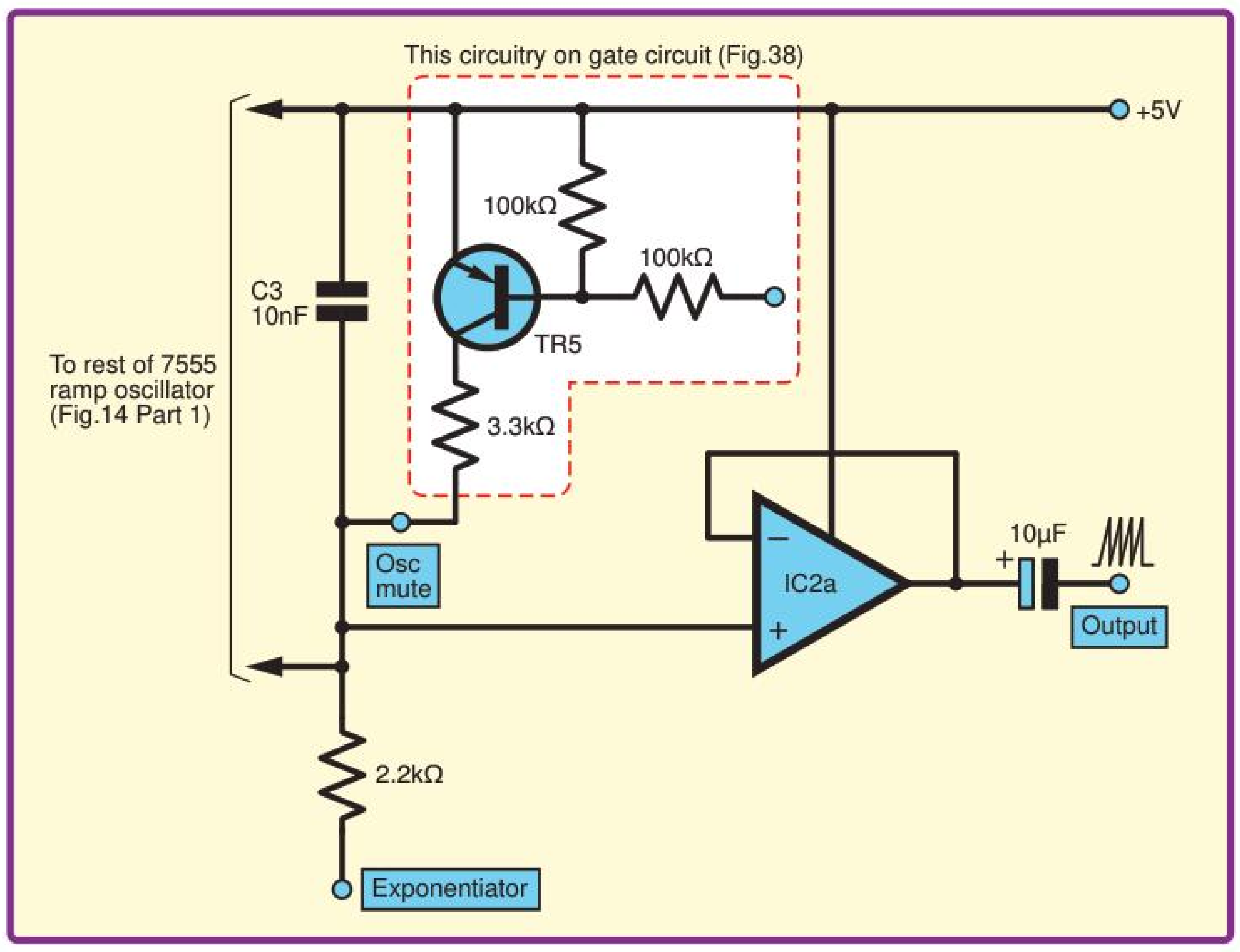

This circuitry on gate circuit (Fig.38)
+5V
100kΩ
100kΩ
C3
10nF
TR5
To rest of 7555 ramp oscillator (Fig.14 Part 1)
3.3kΩ
Osc mute
–
IC2a
+
10µF
Output
2.2kΩ
Exponentiator

Fig.35. To gate the exponential voltage-controlled oscillator a PNP transistor is added.

Generating the gate

To generate a gate signal it is necessary to detect when a note is played. This could be done by detecting the DC control voltage for the VCO with a comparator. However, at the lowest notes the control voltage becomes very low (ie, near 0V) and with the simple single-rail circuits used here there are leakage currents from bias voltages, which can create false triggering.

Old dog learns old trick

One advantage of being a hoarder of ancient magazines and circuits, is that you can find solutions that have been almost forgotten. In the July 1975 issue of *Practical Electronics*, the *Minisonic Synthesiser* by GA Shaw used a trick of riding a high-frequency signal on top of the control voltage. This was then detected to provide the gate signal. What an interesting idea! I had to try it. He used audio techniques using op amps at 40kHz. I decided to use some low-frequency discrete RF circuitry developed for theremins running at 100kHz. I figured this would be less likely to interfere with the 44.1kHz-sampling rate of computer soundcards. I also used a sinewave oscillator to avoid the emissions-compliance testing that square wave switching would require for mass production. It's one of my mottos – always design so you can self-certify.

New keyboard design

Adding the high-frequency signal to the keyboard control voltage can be achieved by injecting it into the bias point of the constant-current generator TR2, as shown in Fig.36. (The Veroboard is shown in Fig.37). This signal is obtained from a Colpitts oscillator built around TR1. This circuit uses an inductor (L1) to form a tuned circuit with the 680pF capacitor.

Inductors are no longer the undesirable circuit elements they once were, and are readily available. They allow greatly reduced power consumption, necessary for battery-powered kit.

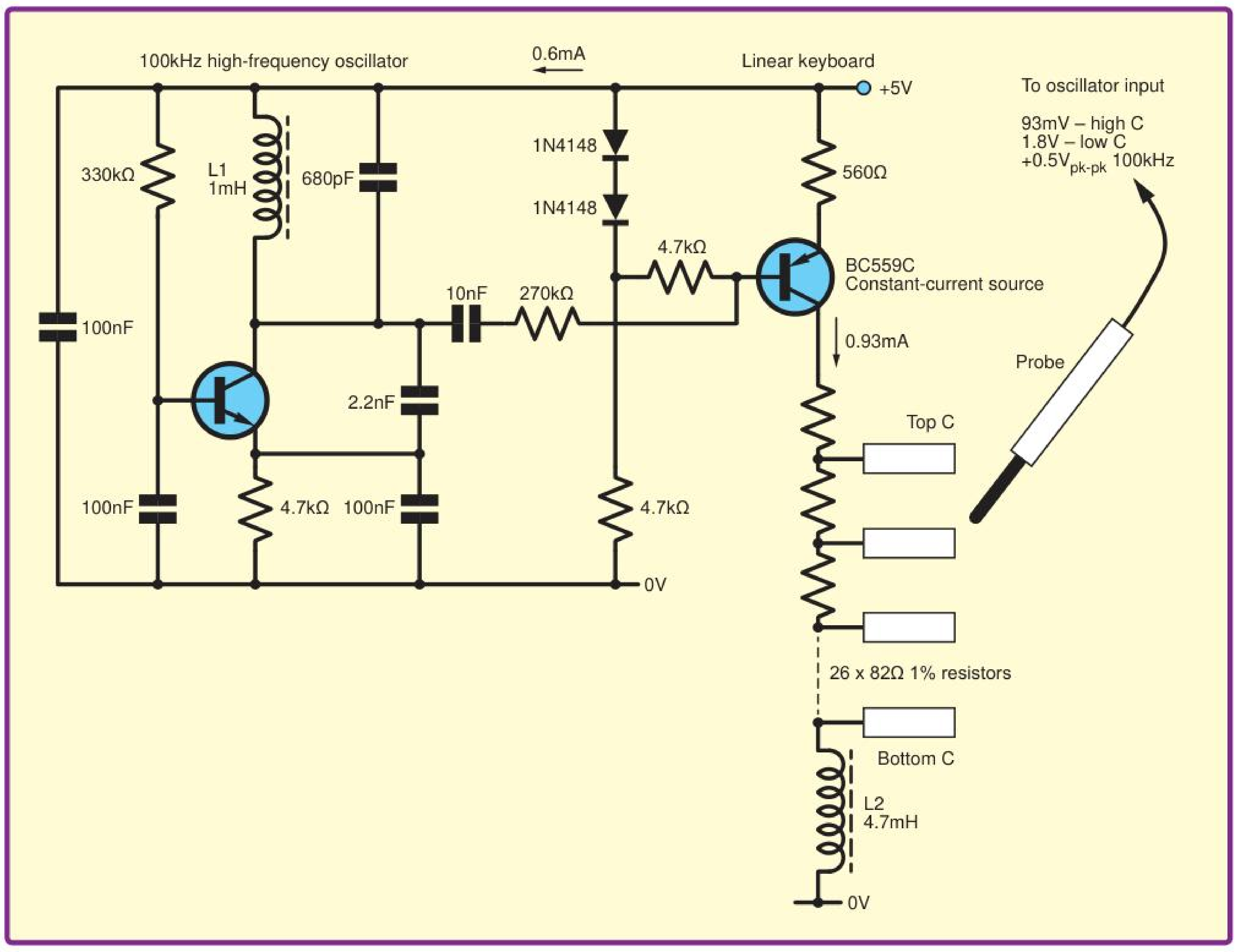

100kHz high-frequency oscillator
0.6mA
Linear keyboard
+5V
To oscillator input
93mV – high C
1.8V – low C
+0.5V pk-pk 100kHz
330kΩ
L1
1mH
680pF
1N4148
1N4148
560Ω
4.7kΩ
BC559C
Constant-current source
10nF
270kΩ
100nF
0.93mA
Probe
2.2nF
Top C
100nF
4.7kΩ
100nF
4.7kΩ
0V
26 x 82Ω 1% resistors
Bottom C
L2
4.7mH
0V

Fig.36. A high-frequency (100kHz) oscillator can be added to the 1/V oct keyboard circuit to avoid extra switch contacts.

Another inductor (L2) is used at the bottom of the resistor chain to prevent the high frequency voltage dropping off towards the lowest notes. This simple idea works because the reactance of the 4.7mH inductor is 3000Ω at 100kHz, while its resistance at DC is only around 40Ω.

Detecting the HF

A simple discrete circuit shown in Fig.38 is used to detect the high-frequency signal present when a note is played. This type of circuitry is very cheap to produce using automated SMT assembly. An HF amplifier based around TR1 feeds into a voltage doubler circuit. The output from this is low-pass filtered and the resulting DC voltage is then amplified and inverted by TR2. Further amplifiers then produce a snap action to provide a gate. The completed gate generator is shown in Fig.39.

House clearance

Before I move on, a quick note about keyboards. In Wales – the 'land of song' – and where I live, sadly lots of old electronic organs are currently being dumped (Fig.40) but they do provide me with plenty of cheap keyboards and springlines. Do note that for 1V/oct analogue keyboards, the contacts need to be low-resistance metal (Fig.41), not the modern conductive paint and rubber types.

Envelope shapers

The standard (proper) full envelope shaper gives a musician control of attack, decay, sustain, and release times; commonly called ADSR, as shown in Fig.42. Simple envelope shapers just offer attack and decay control, which is the minimum needed for a musical sound. This enables a plausible starting transient to be created, simulating string plucking or a percussive hit. The 'Stylophone' just has gate on/off, the absolute minimum!

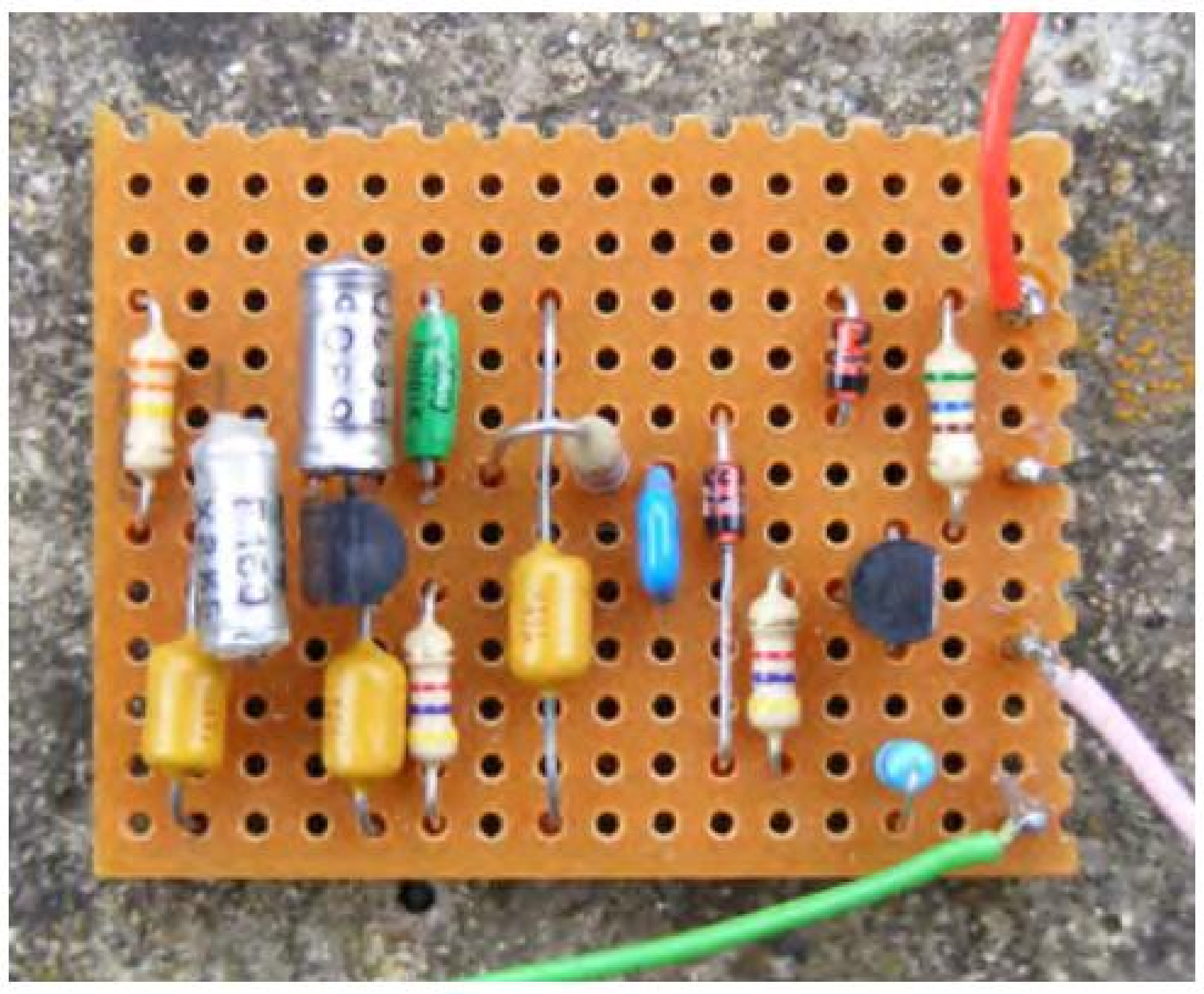


Fig.37. Keyboard module with high frequency oscillator (note the green axial inductor).

Interestingly, the electrical contact noise and DC step glitch of the Stylophone's probe is not a 'bad' thing; as it provides an element of attack and decay transients, as shown in the signal screen grabs in Fig.43. Simple envelopes can sound surprisingly good if a bit of reverb or echo is provided, because this can provide the illusion of release and space. This is especially helpful in monophonic instruments where only one note can be played at a time. In the Gen X-1 I used a low-cost digital delay line based on the PT2399 chip. 'Release' is where the sound continues, decaying after the note has stopped being played, as in a piano with the sustain pedal pressed. For this to work, an extra circuit block is needed to hold the note. I'll do a more complex true ADSR using the trusty 7555 at some point.

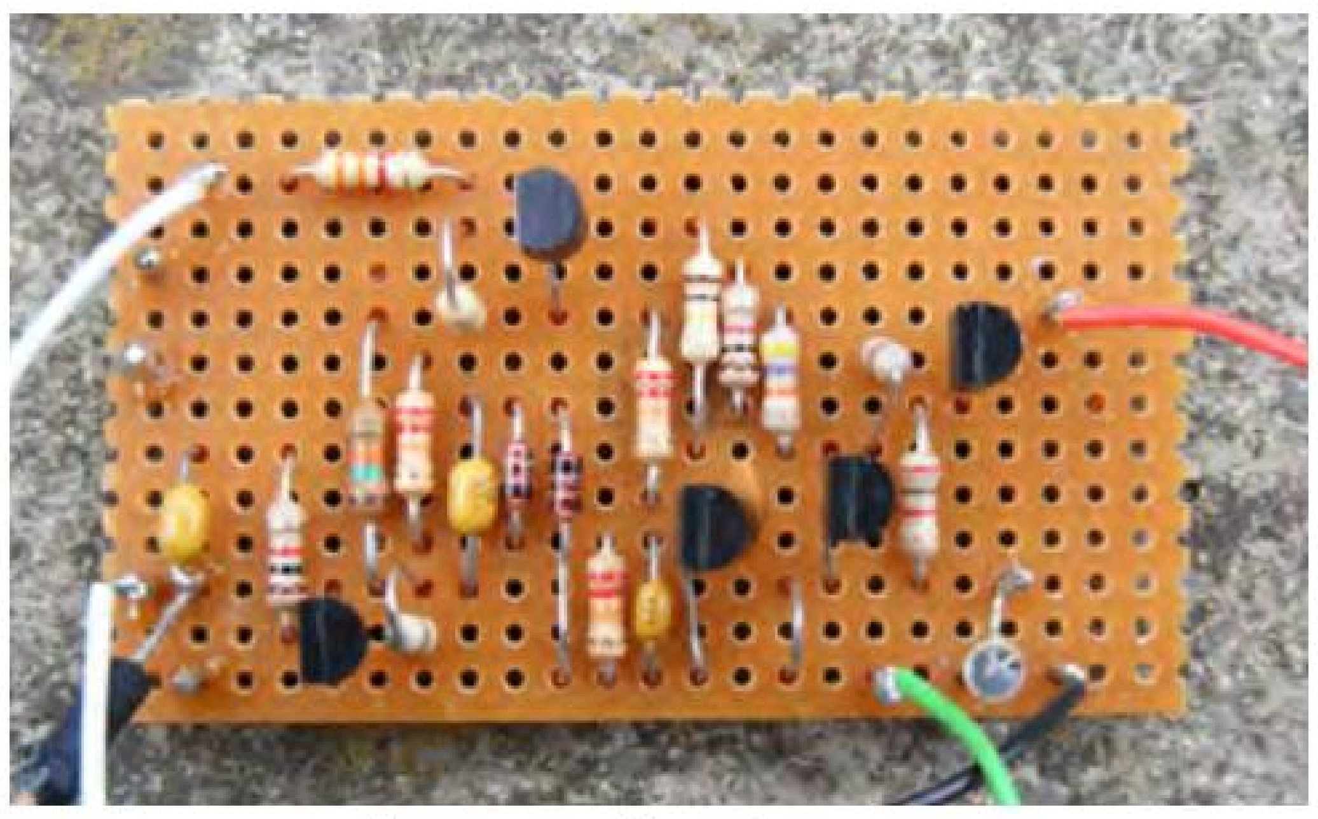


Fig.39. The completed gate generator.

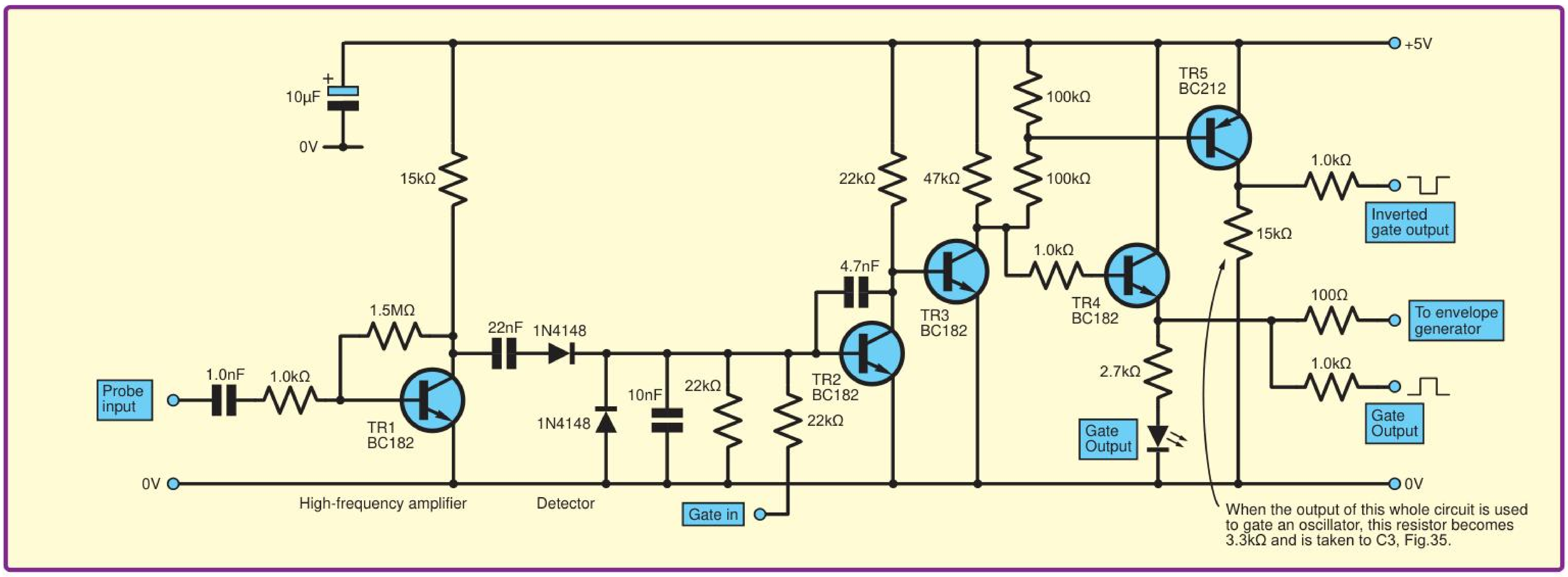

+5V
10µF
0V
15kΩ
22kΩ
47kΩ
100kΩ
100kΩ
TR5
BC212
1.0kΩ
Inverted gate output
15kΩ
4.7nF
1.0kΩ
1.5MΩ
22nF
1N4148
TR3
BC182
TR4
BC182
100Ω
To envelope generator
Probe input
1.0nF
1.0kΩ
TR1
BC182
10nF
22kΩ
1N4148
TR2
BC182
22kΩ
2.7kΩ
1.0kΩ
Gate Output
Gate Output
0V
0V
High-frequency amplifier
Detector
Gate in
When the output of this whole circuit is used to gate an oscillator, this resistor becomes 3.3kΩ and is taken to C3, Fig.35.

Fig.38. High-frequency-detector gate-generation circuit.

Fig.40. Discarded old electronic organs are an ideal source of free or very cheap keyboards.

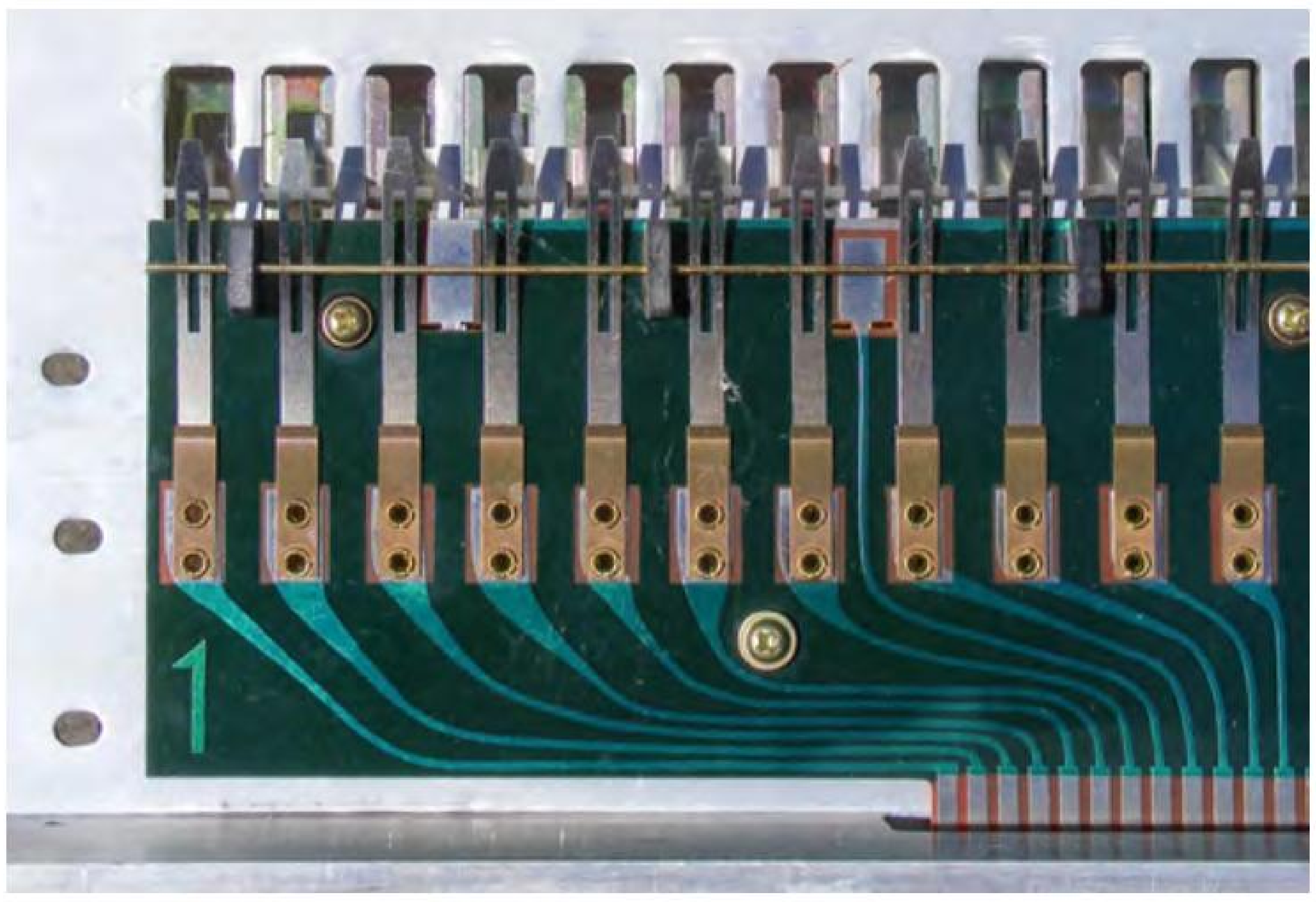


Fig.41. Analogue 1V/octave keyboards need low-resistance metal contacts such as these.

Sample and hold

To store the note voltage, a form of analogue memory is needed; this is simply a low-leakage capacitor buffered by a high-impedance FET input op amp. Here, the oscillator runs continuously, the hold function allowing the correct note to be held after the key is released. It then goes to the new value when the next note is pressed. There is a limit to how long this can be, sample and hold tends to become 'sample and droop' after capacitor, op amp and board leakage currents take effect in a real circuit. A sample-and-hold circuit applicable to the 'Stylophone' is shown in Fig.44.

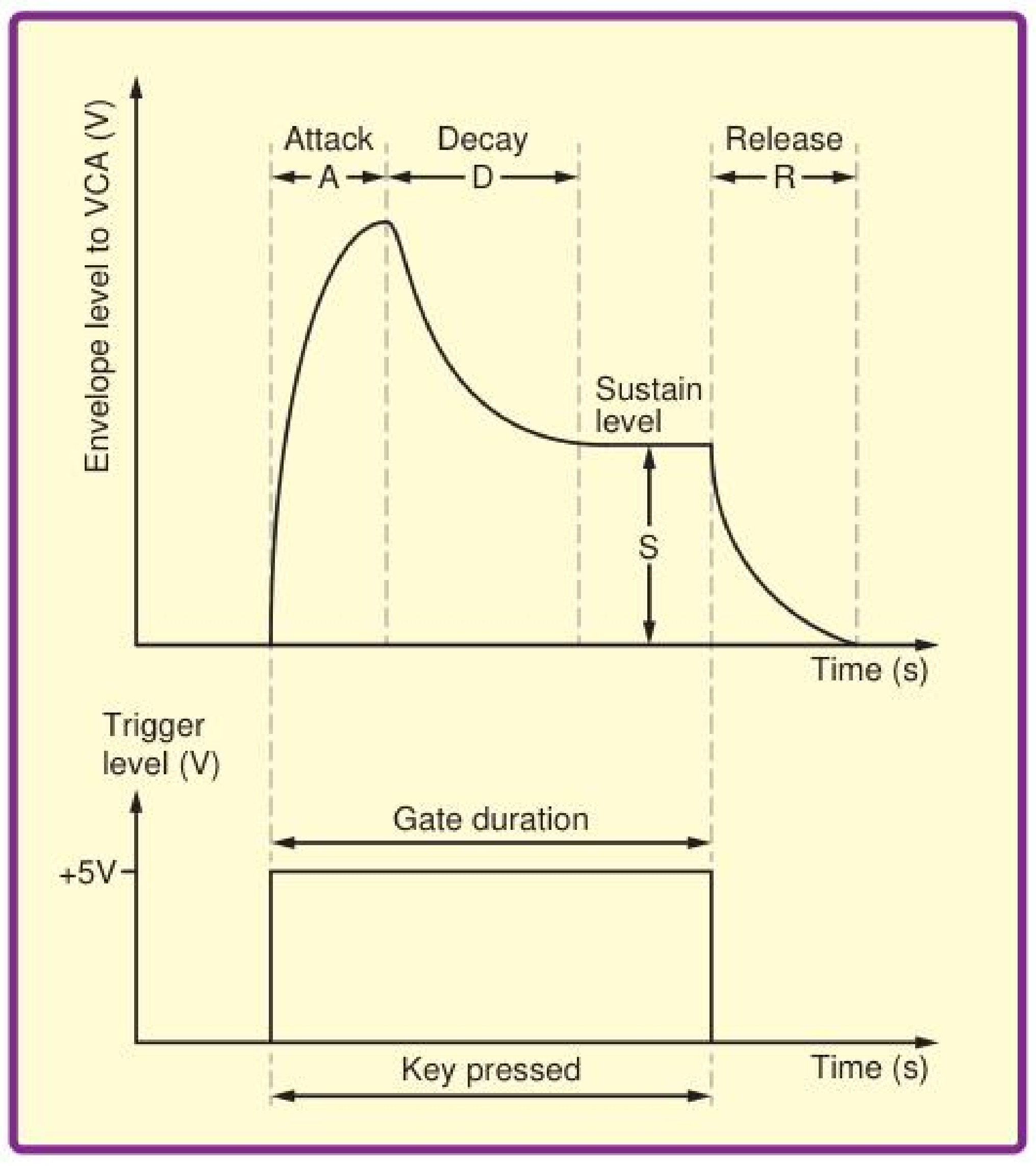

Envelope level to VCA (V)
Attack
A
Decay
D
Release
R
Sustain level
S
Time (s)
Trigger level (V)
Gate duration
+5V
Key pressed
Time (s)

Fig.42. The standard envelope structure for professional analogue synthesisers.

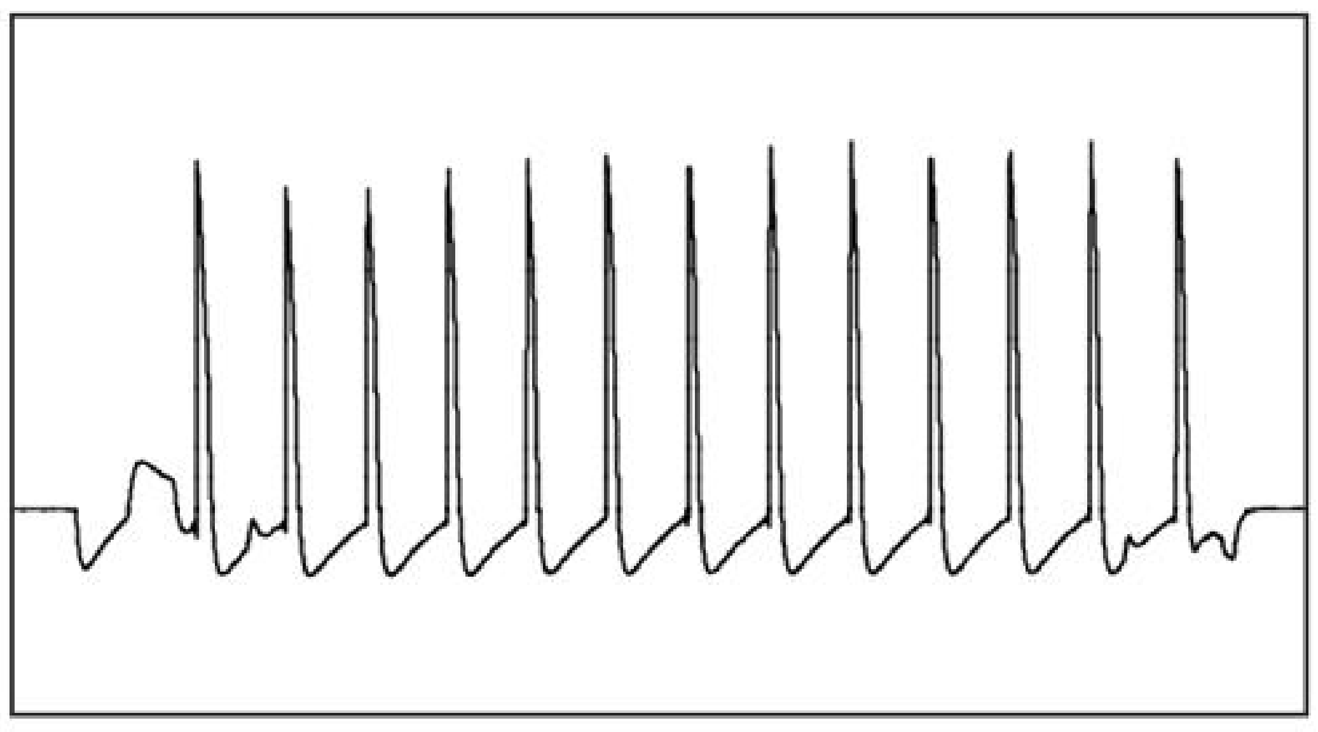


Fig.43. A screen shot of a Stylophone note being played. The glitches at the beginning and end are not defects, but add sonic 'character' because they are different each time.

It is necessary to use a MOSFET op amp, such as the Microchip MCP6001/2, since it must have very low leakage and be able to work down to ground. The capacitor should have low leakage and dielectric absorption; for example, polystyrene, polycarbonate or polypropylene devices. There is the usual design conflict – if the capacitance is too small the droop will be worse, but if it is too large then charging will be slow, causing a short frequency dip at the start of notes. I settled on 33nF. An improvement would be a buffer stage that can supply high peak currents, since the keyboard can only give about 0.8mA. This is okay for a cheap synthesiser, and the input to the sample and hold can go directly to the probe.

The 47nF capacitor and 2.2kΩ resistor filters out any of the HF gate signal, which could cause offsets from rectification. This also provides static protection. Putting a pot in series with the probe will vary the charge/discharge time giving slewing or 'glide' between notes.

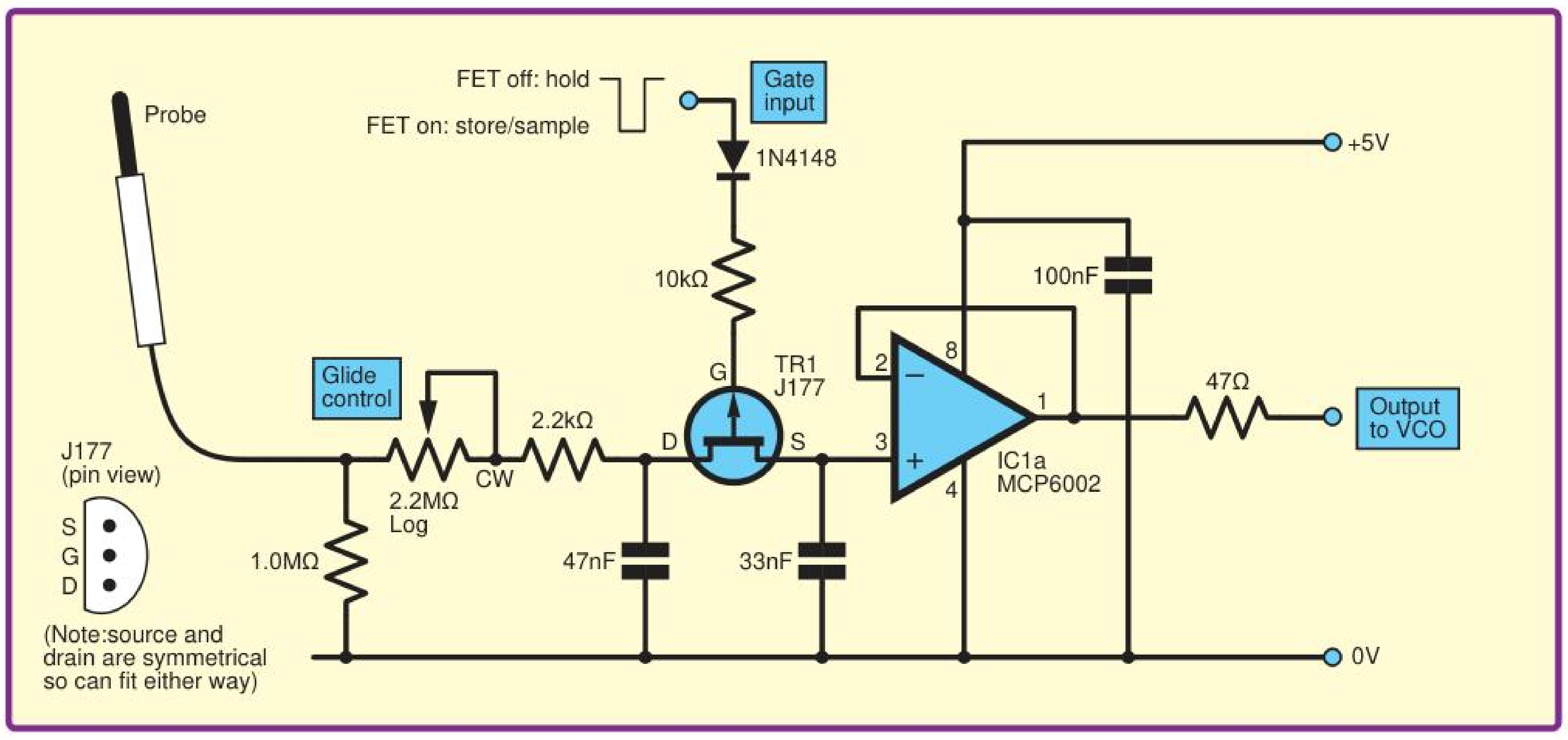

Probe
FET off: hold
FET on: store/sample
Gate input
1N4148
+5V
10kΩ
100nF
Glide control
G
TR1
J177
2
8
47Ω
2.2kΩ
D
S
1
Output to VCO
J177 (pin view)
S
G
D
CW
2.2MΩ Log
3
+
IC1a
MCP6002
4
1.0MΩ
47nF
33nF
(Note:source and drain are symmetrical so can fit either way)
0V

Fig.44. The sample-and-hold circuit – tricky high impedance design.

If the probe is touched or grounded between notes, leakage and hum can take place. To prevent this, the probe can is disconnected between notes by using a P-channel J-FET. Its gate is pulled low by the keyboard gate output to acquire the keyboard voltage when the probe is touched on a note. Between notes, the gate is pulled high to bias the FET off. The diode prevents forward biasing of the gate junction from the held voltage, which will allow leakage. A low pinch-off voltage (V_p) FET of around 1.8V, such as a J177 should be used to ensure it is biased off at high keyboard voltages and at the low supply voltage of 5V. The circuit is shown in Fig.45.

Voltage-controlled amplifiers

The simplest voltage-controlled amplifier (VCA) is a light-dependant resistor (LDR) controlled by an LED – this is really a voltage-controlled *attenuator* and these are still used in analogue compressors. For synthesisers, a circuit with more consistency

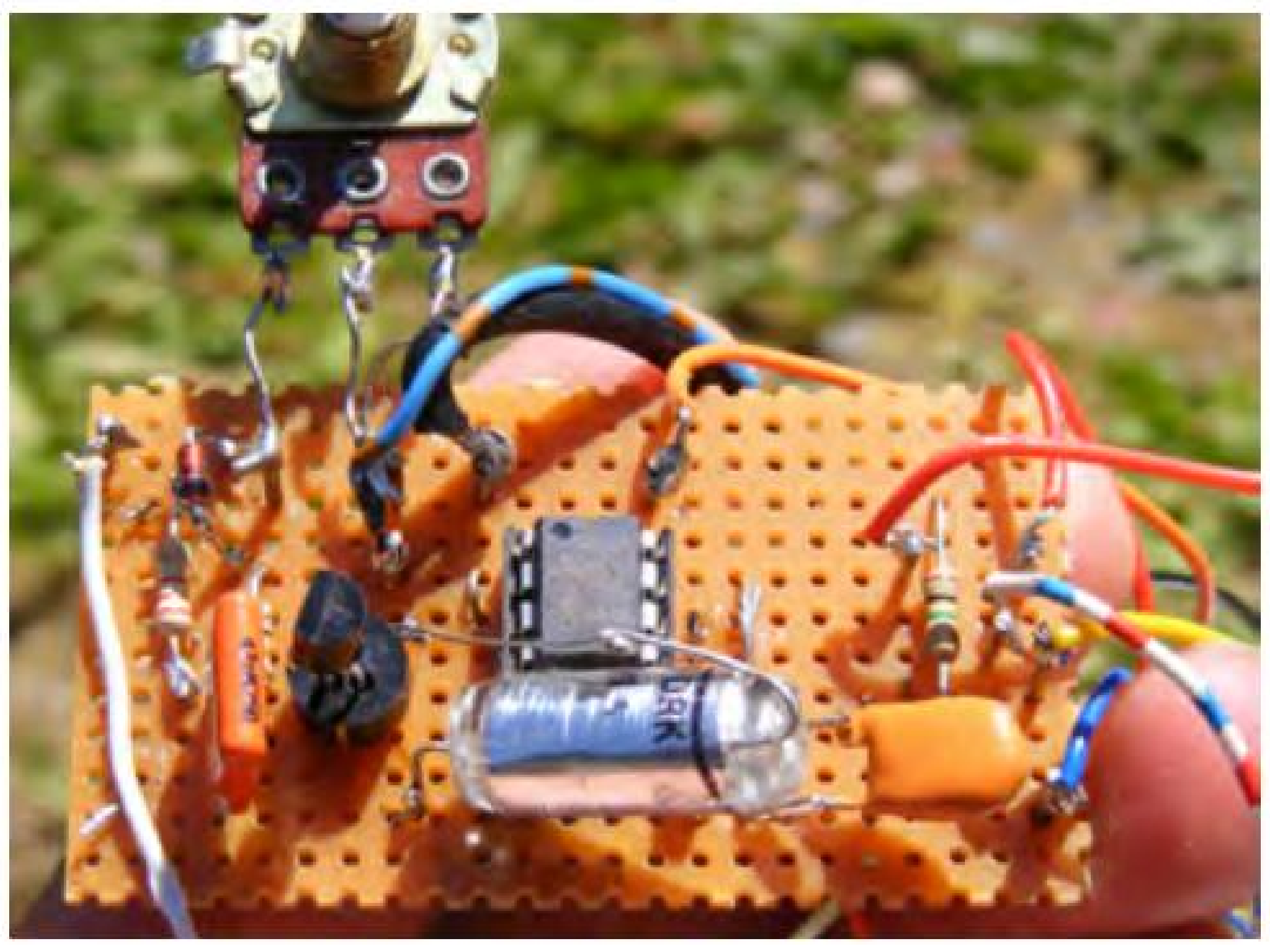


Fig.45. Completed sample-and-hold board – note the socket for the FET and the large polystyrene 'hold' capacitor. The rather messy construction is a reflection of my endless tweaking and experimentation. I will rebuild and clean off leakage-causing flux residue.

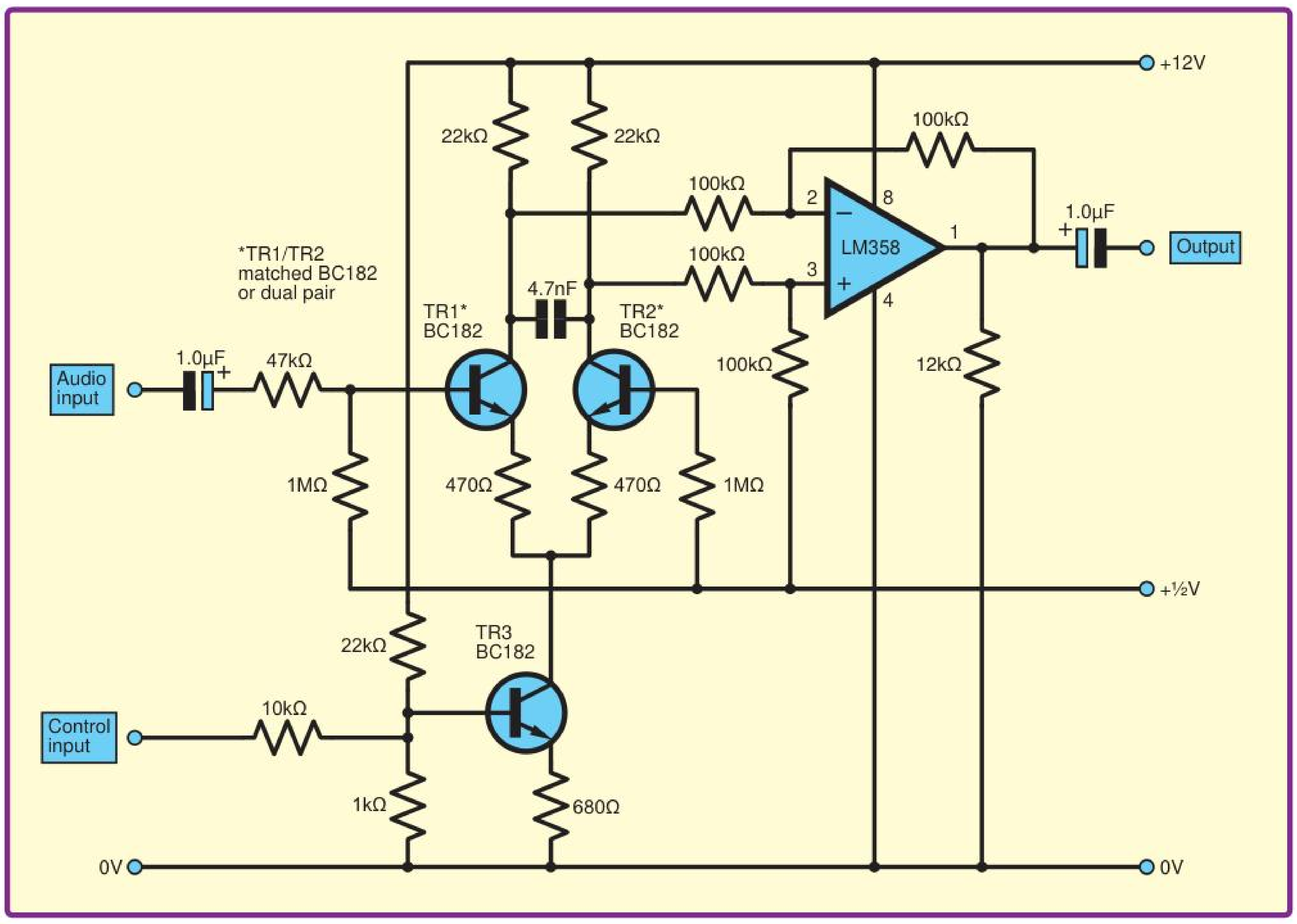


Fig.46. Discrete-transistor VCA. This approach is very cheap with SMT components, but suffers from control voltage breakthrough.

is needed. These are usually based on the variation of transistor transconductance (gain in mA/V) with collector current. However, the problem with these circuits is that the control voltage directly appears on the output unless careful balancing and cancellation techniques are used. The simplest circuit is shown in Fig.46. This is based on our old friend the long-tailed pair (see *Variable audio filters – Part 2*, *EPE*, May 2018) and was used in musical instruments, such as the PAiA Theramax theremin.

The VCA is generally the last link in the chain since it blocks any noise when it's muted. The noise from resonant filters is particularly noticeable which is why the VCF is generally just before the VCA. Of course, with a modular synthesiser the positions can be reversed if the overload characteristic of the filter needs to be exploited.

Log/lin confusion

There is confusion with the terms 'log' (logarithmic) and 'exponential' in the audio world, and the two terms are often used interchangeably. A 'log VCA' is actually an 'exponential VCA', where a linear increase in control voltage causes an exponential rise in gain. Likewise, a so-called 'log' volume potentiometer gives the same mathematical response as it is rotated clockwise. True logarithmic amplifiers are mainly used for peak programme meters and some compressors, where the scale is in even decibel steps.

The most common VCA ICs used in synthesisers are operational transconductance amplifiers (OTAs), usually the LM13600/700 (there is little else to choose from since the CA3080 has been discontinued). These consist of two 3080 chip masks and two Darlington transistor buffers on one chip. OTAs have a linear gain change characteristic, so in theory an exponential converter is needed. Most synth designers don't bother however, relying on the exponential charge/discharge of the capacitors in the envelope generators (Fig.47). Although the curve of the capacitor goes the 'wrong' way for the attack part of the curve (the rate of voltage increase going down as the capacitor charges up) it's correct for the decay and release parts, and it sounds good. Since the attack part is usually quick or mainly under control of the player by blowing, bowing or swell pedals, this theoretical drawback does not seem to be practically important.

Possibly the best effect comes from using constant current charge-discharge of the capacitors to give a straight charging characteristic, controlling an exponential VCA. This of course complicates the circuitry. It is possible to use log VCA chips, such as the THAT 2080, but these cost four-times more per section than the LM13600/700, and their Hi-Fi specifications are superfluous in a synthesiser. In fact, a few per cent harmonic distortion is more likely to be enhancing; plus, with a signal level of a few volts, noise is fairly insignificant.

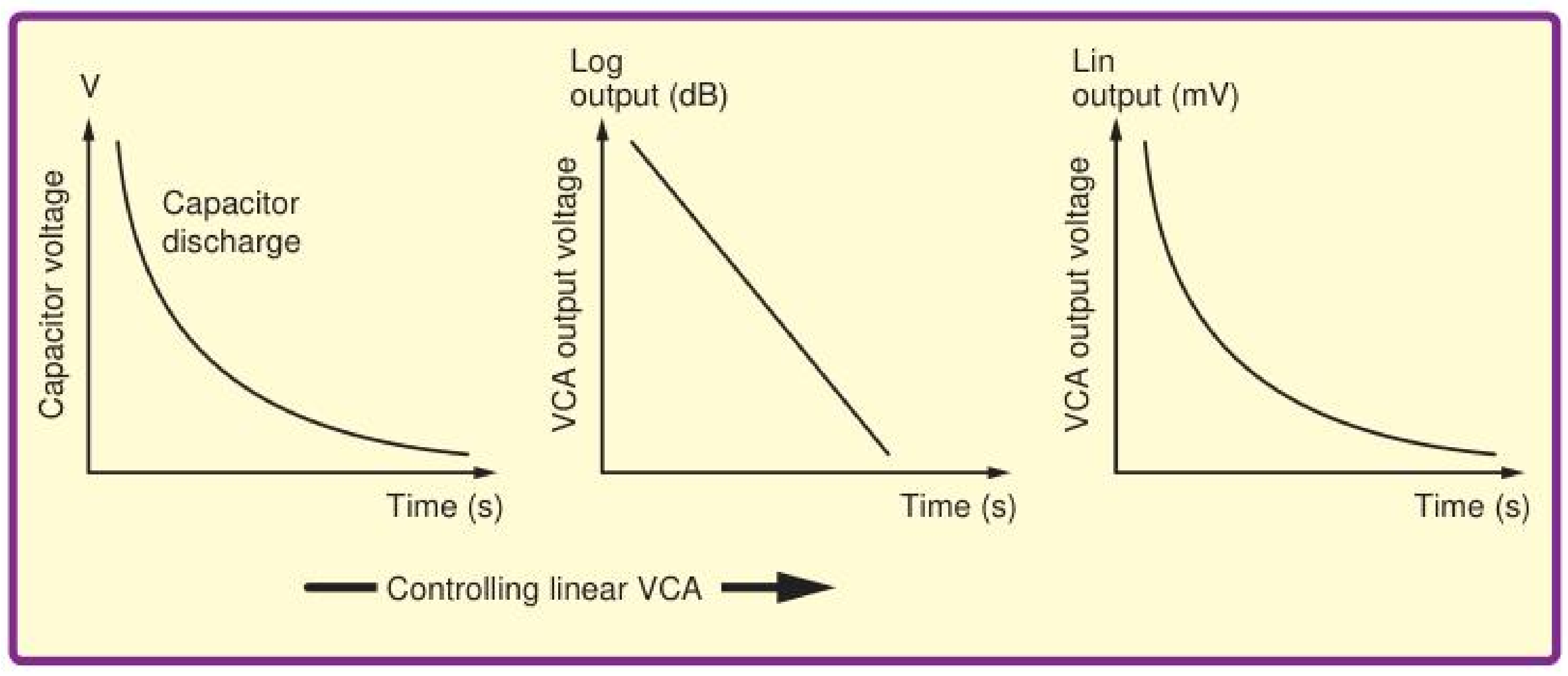


Fig.47. The exponential decay of capacitor voltage yields a natural decay of amplitude with linear control VCAs.

It's necessary to use constant-current discharge from the capacitor (Fig.48) with logarithmic VCAs, since two exponential responses (capacitor and log VCA) would sound artificial. When VCAs are modulated the effect is better in log mode if sinusoidal low-frequency oscillators (LFOs) are used. The new Cool Audio V2164 chip is worthy of investigation, since it has four log VCAs on one chip. It is used in the Lil' Erebus DIY synth from Dreadbox in Greece.

Practical VCA

A circuit for a VCA using the LM series chip is shown in Fig.49. Note the linearising diodes on the inputs are not used because they increase current consumption by an extra 2mA and every mA counts with battery-operated consumer gear. They also reduce the gain. Also, the higher gradual distortion curve sounds better. OTAs are limited to inputs of around $50mV_{pk-pk}$ before soft clipping commences and therefore need an attenuator on the input. Unfortunately, this process of attenuation followed by gain results in a poor signal-to-noise ratio. The resistors on this VCA give unity gain with the outputs of the VCO and gate. Note the LM13600 is a dual chip. The built circuit is shown in Fig.50.

The simplest envelope generator is shown in Fig.51, incorporating just attack and release. The only unusual element is the transistor, which is biased off when the gate is high. When the key

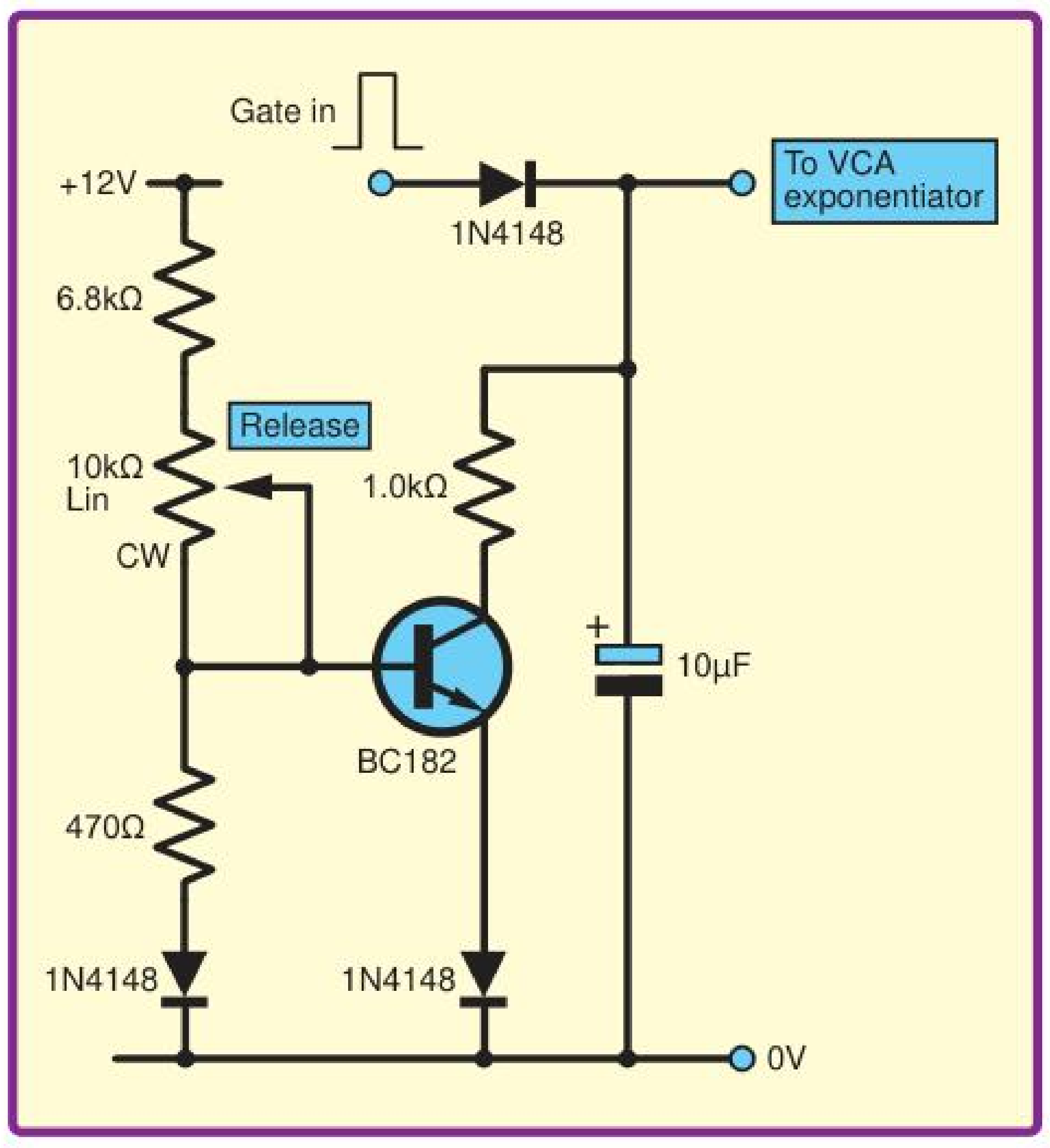


Fig.48. Constant-current discharge of capacitor to give proper release with exponential VCAs.

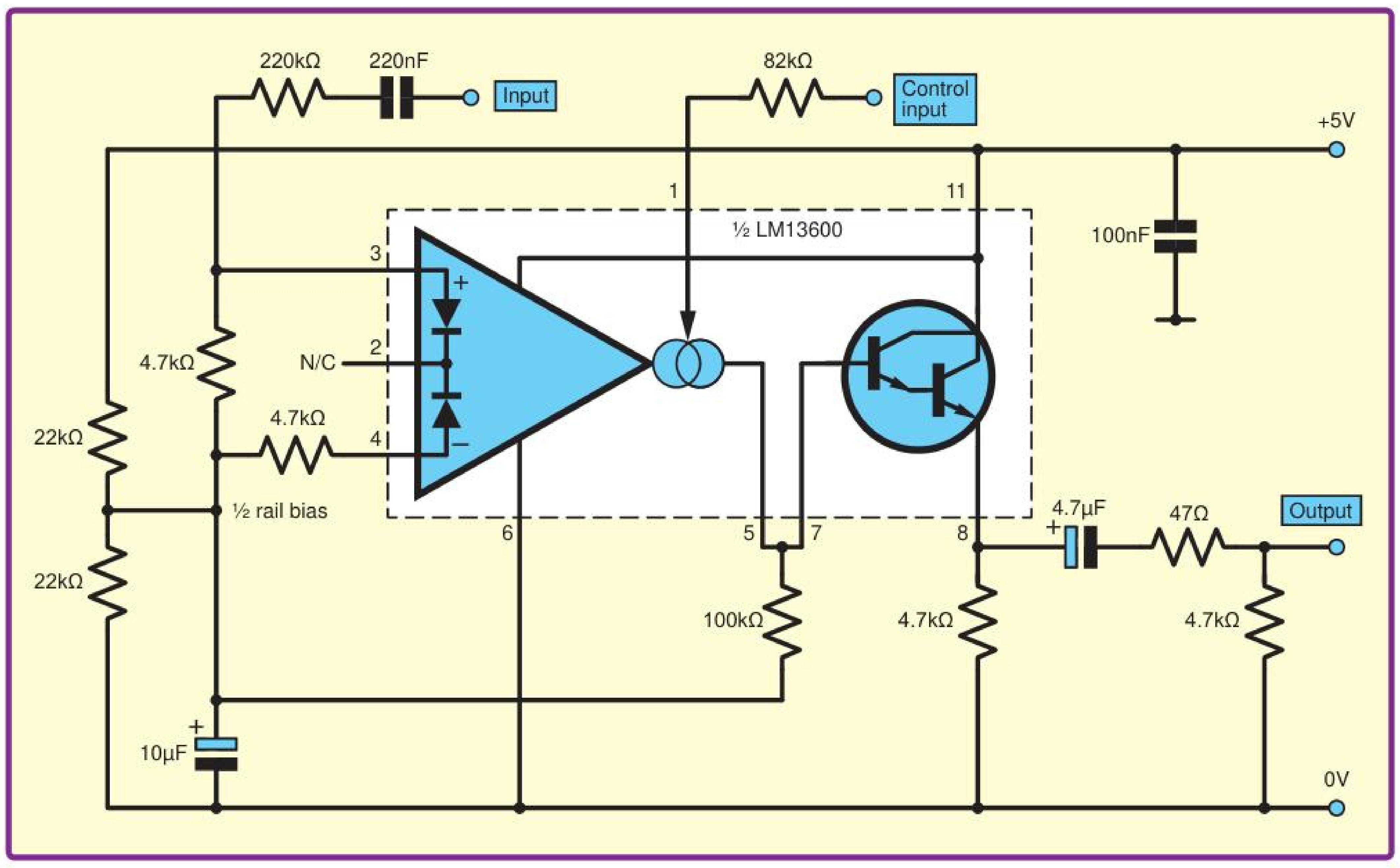

220kΩ
220nF
Input
82kΩ
Control input
+5V
1
11
½ LM13600
100nF
3
+
4.7kΩ
N/C
2
4.7kΩ
4
–
22kΩ
½ rail bias
6
5
7
8
4.7µF
+
47Ω
Output
22kΩ
100kΩ
4.7kΩ
4.7kΩ
+
10µF
0V

Fig.49. A VCA based on the LM13600. Note the 100kΩ load resistor needs to go to the half-rail bias (½V) point to avoid thumps.

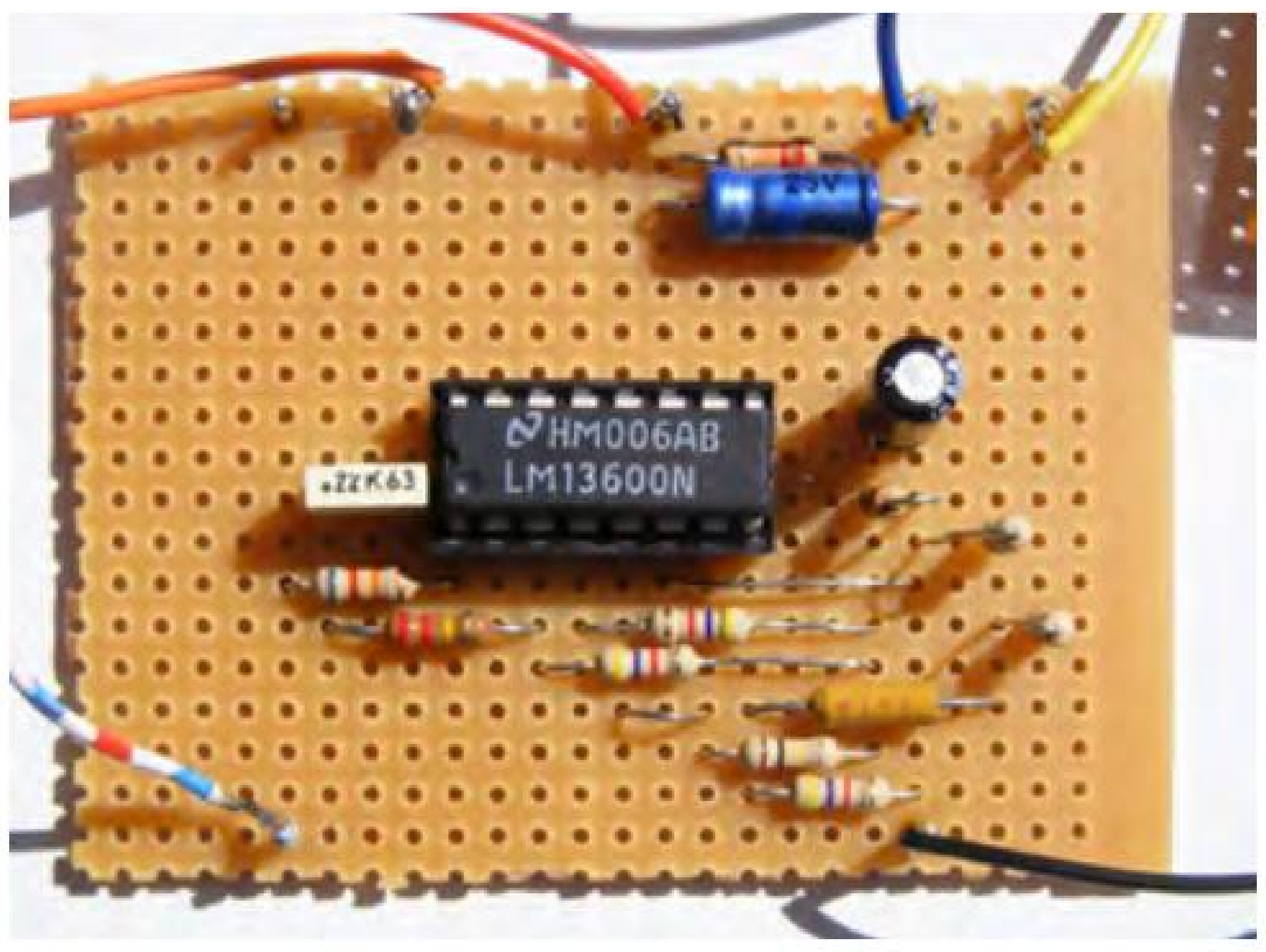

HM006AB
LM13600N

Fig.50. The VCA constructed on Veroboard. Note one half of the chip is not used; it is being saved for the voltage-controlled filter (VCF).

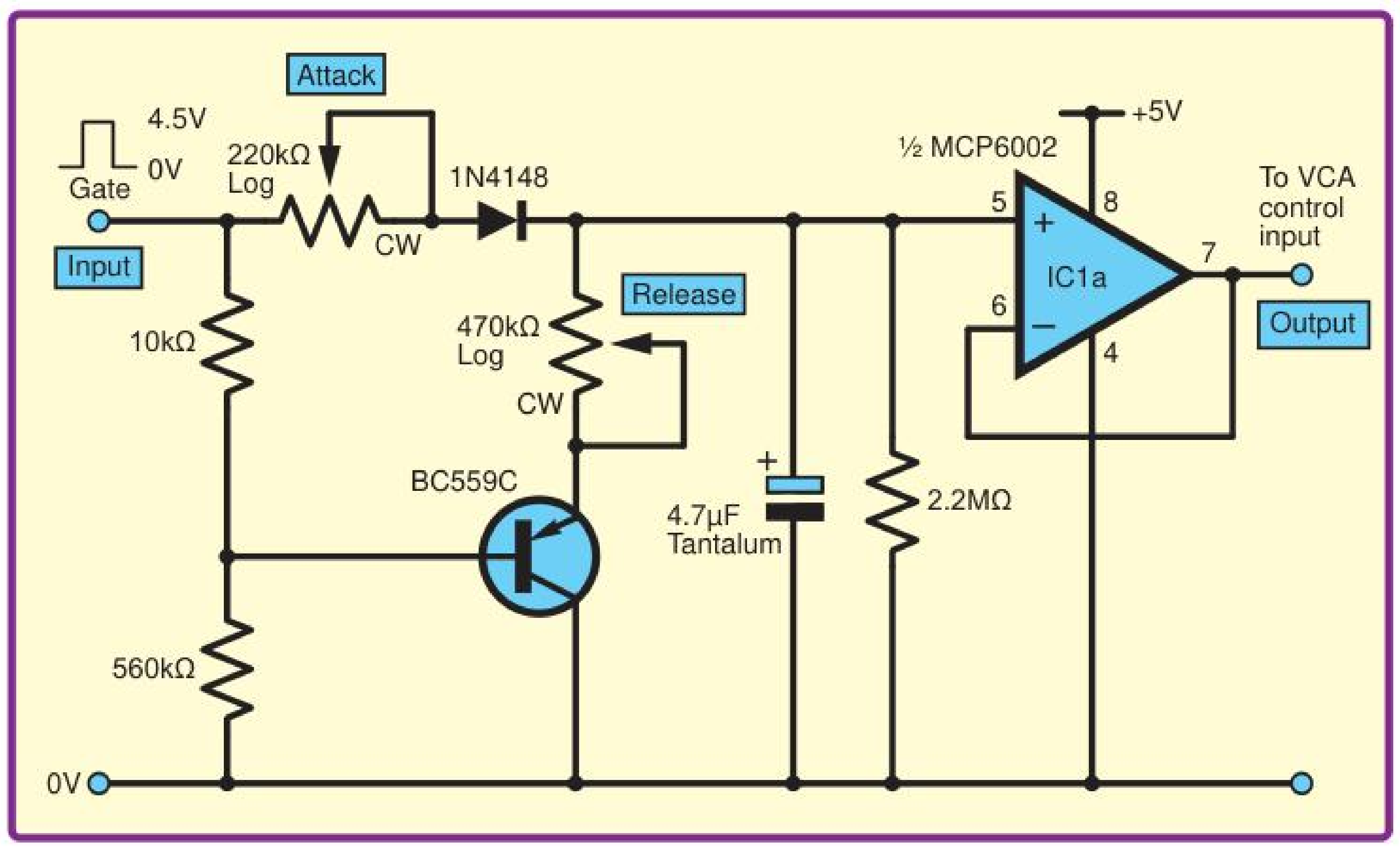

Attack
4.5V
0V
Gate
220kΩ
Log
CW
1N4148
Input
10kΩ
470kΩ
Log
CW
Release
BC559C
+
4.7µF
Tantalum
2.2MΩ
560kΩ
0V
½ MCP6002
+5V
5
8
+
IC1a
6
–
4
7
To VCA
control
input
Output

Fig.51. A simple attack/release generator – use a tantalum timing capacitor for low leakage.

is released the gate goes low and the transistor turns on, discharging the capacitor, and giving a controlled release. The envelope generator board is shown in Fig.52. A basic synthesiser based on the simple Veroboard HF keyboard, VCO, VCA, gate and AR modules described is shown in Fig.53.

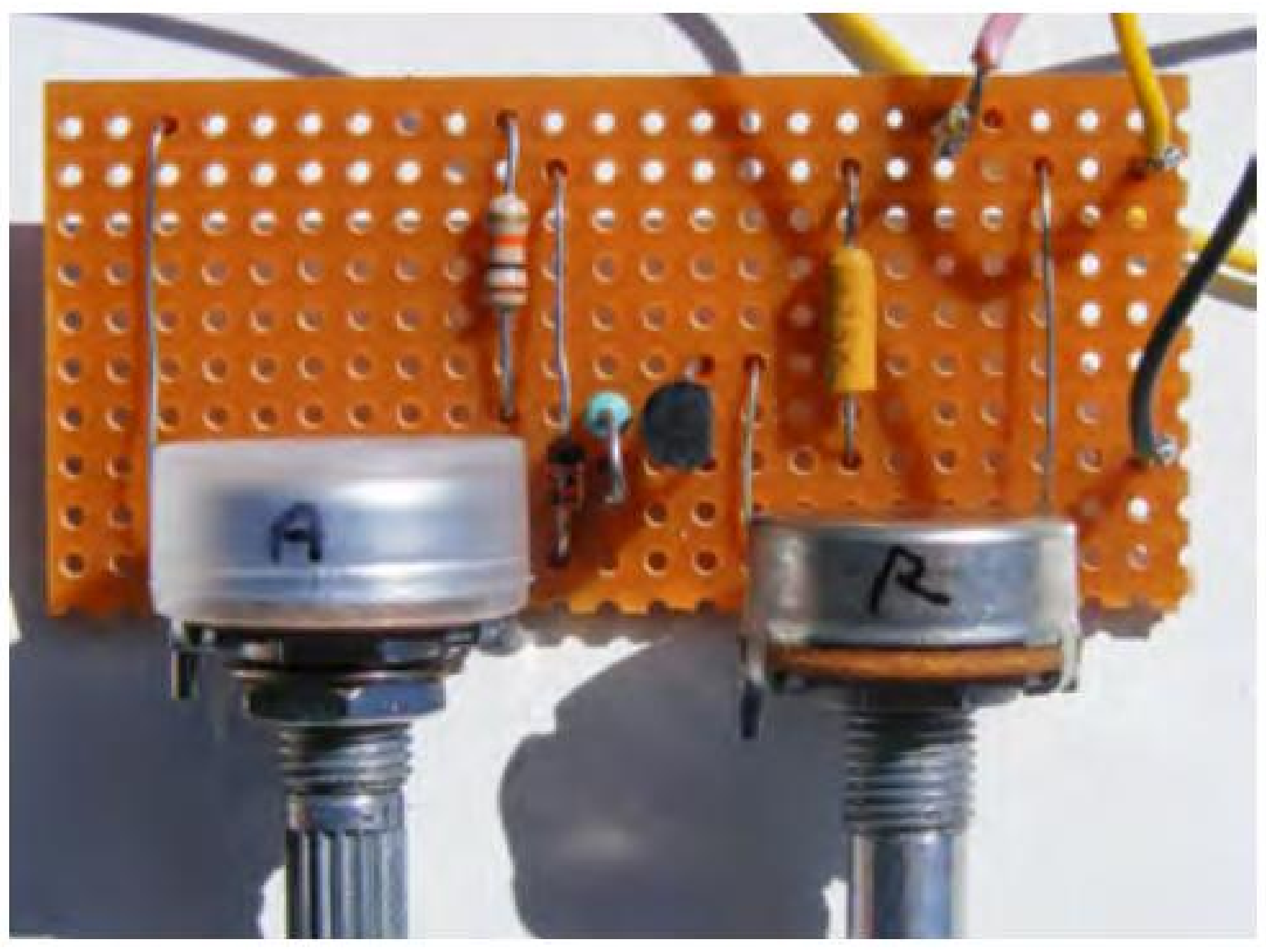
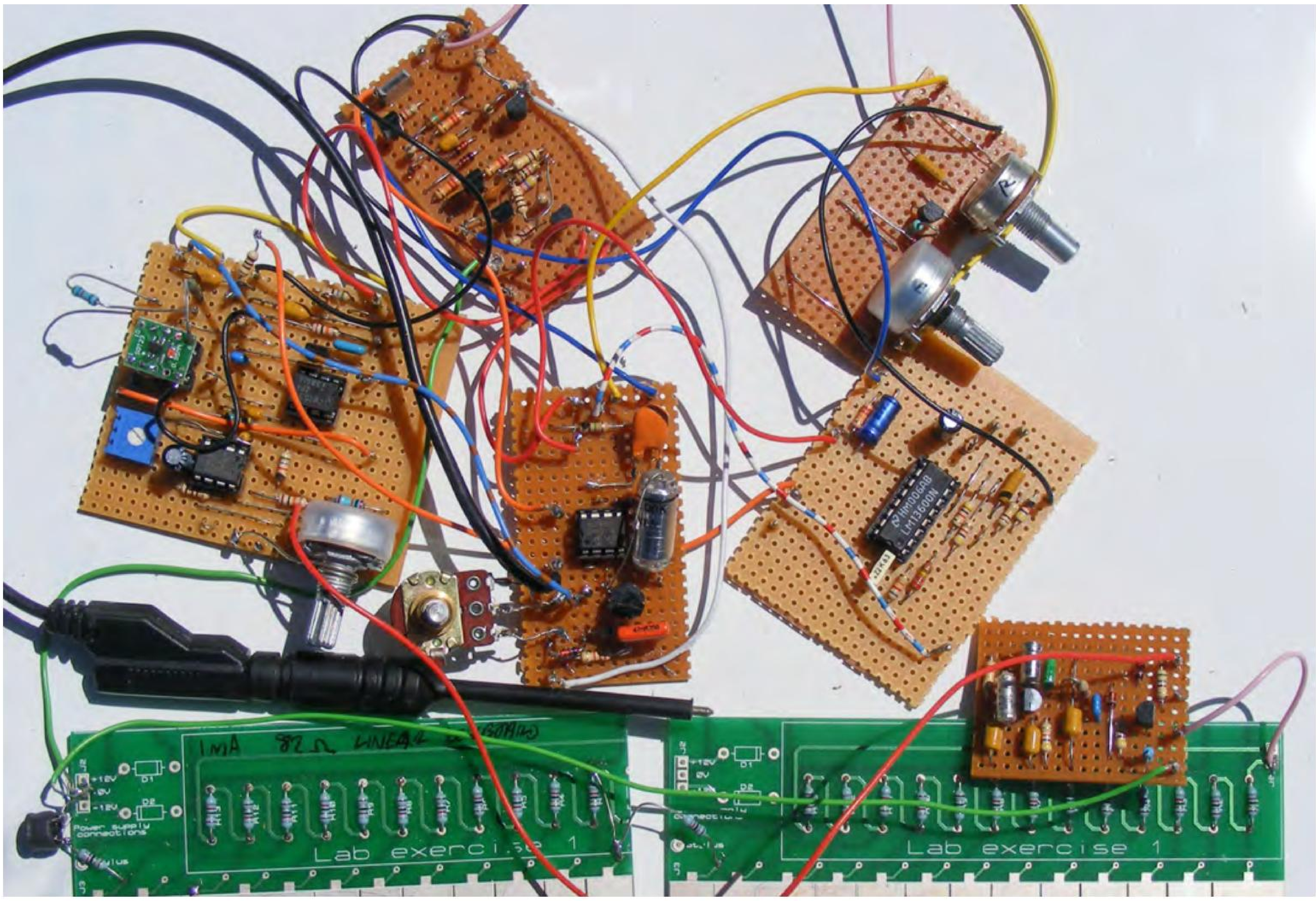


Fig.52. The completed AR generator module.

Next month

In *Part 3*, we'll add the final building block for our simple DIY approach to making an analogue synthesiser – a variable filter. With all the parts in place we will then create our first instrument.

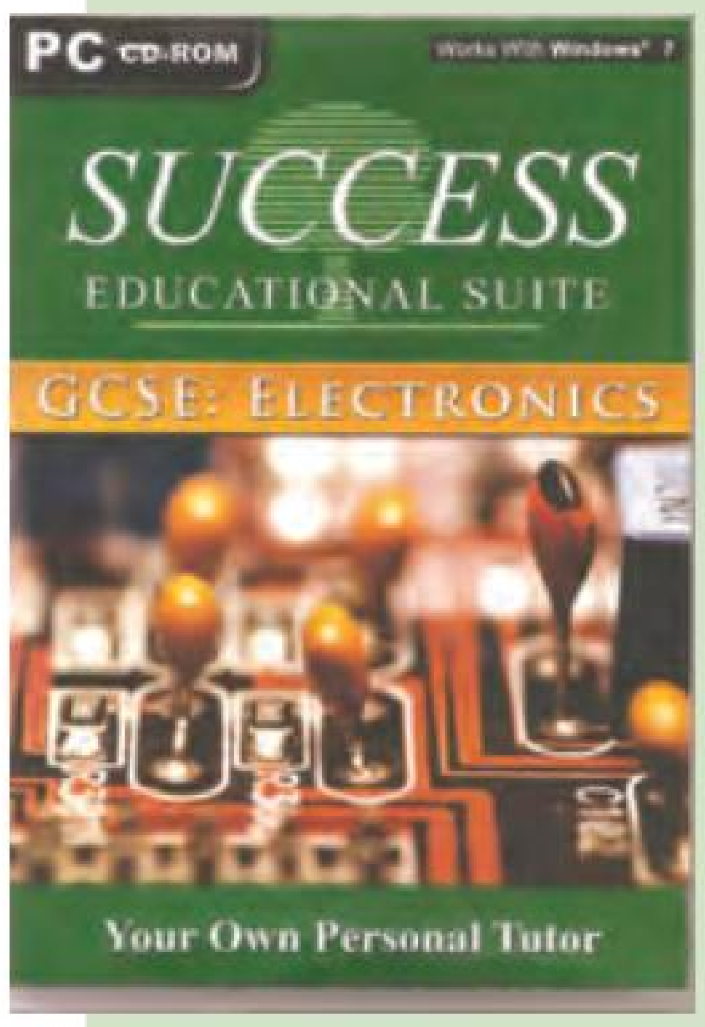
Fig.53. (Below) This tangle of Veroboard modules (described in this article) could be the beginning of the Gen X-2.


Lab exercise 1
Lab exercise 1

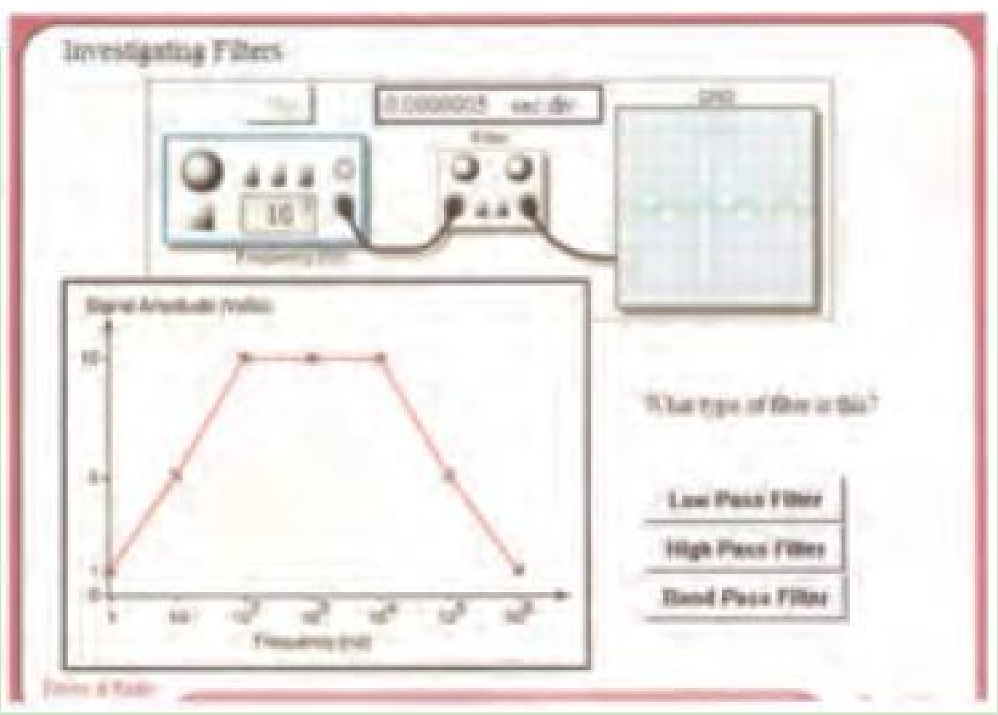
EPE IS PLEASED TO BE ABLE TO OFFER YOU THESE

ELECTRONICS CD-ROMS

GCSE ELECTRONICS



£12.50
inc. VAT and P&P



Suitable for any student who is serious about studying and who wants to achieve the best grade possible. Each program's clear, patient and structured delivery will aid understanding of electronics and assist in developing a confident approach to answering GCSE questions. The CD-ROM will be invaluable to anyone studying electronics, not just GCSE students.

***** ***Contains comprehensive teaching material to cover the National Curriculum syllabus*** ***** ***Regular exercises reinforce the teaching points*** ***** ***Retains student interest with high quality animation and graphics*** ***** ***Stimulates learning through interactive exercises*** ***** ***Provides sample examination ques-tions with model solutions*** ***** ***Authored by practising teachers*** ***** ***Covers all UK examination board syllabuses*** ***** ***Caters for all levels of ability*** ***** ***Useful for self-tuition and revision***

SUBJECTS COVERED

Electric Circuits – Logic Gates – Capacitors & Inductors – Relays – Transistors – Electric Transducers – Operational Amplifiers – Radio Circuits – Test Instruments

Over 100 different sections under the above headings

CIRCUIT WIZARD

Circuit Wizard is a revolutionary software system that combines circuit design, PCB design, simulation and CAD/CAM manufacture in one complete package. Two versions are available, Standard or Professional.

By integrating the entire design process, Circuit Wizard provides you with all the tools necessary to produce an electronics project from start to finish – even including on-screen testing of the PCB prior to construction!

** Circuit diagram design with component library (500 components Standard,1500 components Professional) * Virtual instruments (4 Standard, 7 professional) * On-screen animation * Interactive circuit diagram simulation * True analogue/digital simulation * Simulation of component destruction * PCB Layout * Interactive PCB layout simulation * Automatic PCB routing * Gerber export * Multi-level zoom (25% to 1000%) * Multiple undo and redo * Copy and paste to other software * Multiple document support*

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

Standard **£61.25** inc. VAT. Professional **£75** plus VAT.

From £49.00

TINA Design Suite V11

FEATURED IN OUR TEACH-IN 2015 SERIES

Analogue, Digital, Symbolic, RF, MCU and Mixed-Mode Circuit Simulation and PCB Design with TINA

TINA Design Suite V11 is a powerful yet affordable software package for analysing, designing and real time testing analogue, digital, MCU, and mixed electronic circuits and their PCB layouts. You can also analyse RF, communication, optoelectronic circuits, test and debug microcontroller applications.

Enter and analyse any circuit up to 100 nodes (student), or 200 with the Basic (Hobbyist) version within minutes with TINA's easy-to-use schematic editor. Enhance your schematics by adding text and graphics. Choose components from the large library containing more than 10,000 manufacturer models. Analyse your circuit through more than 20 different analysis modes or with 10 high tech virtual instruments.

Present your results in TINA's sophisticated diagram windows, on virtual instruments, or in the live interactive mode where you can even edit your circuit during operation.

Customise presentations using TINA's advanced drawing tools to control text, fonts, axes, line width, colour and layout. You can create and print documents directly inside TINA or cut and paste your results into your favourite word procesing or DTP package.

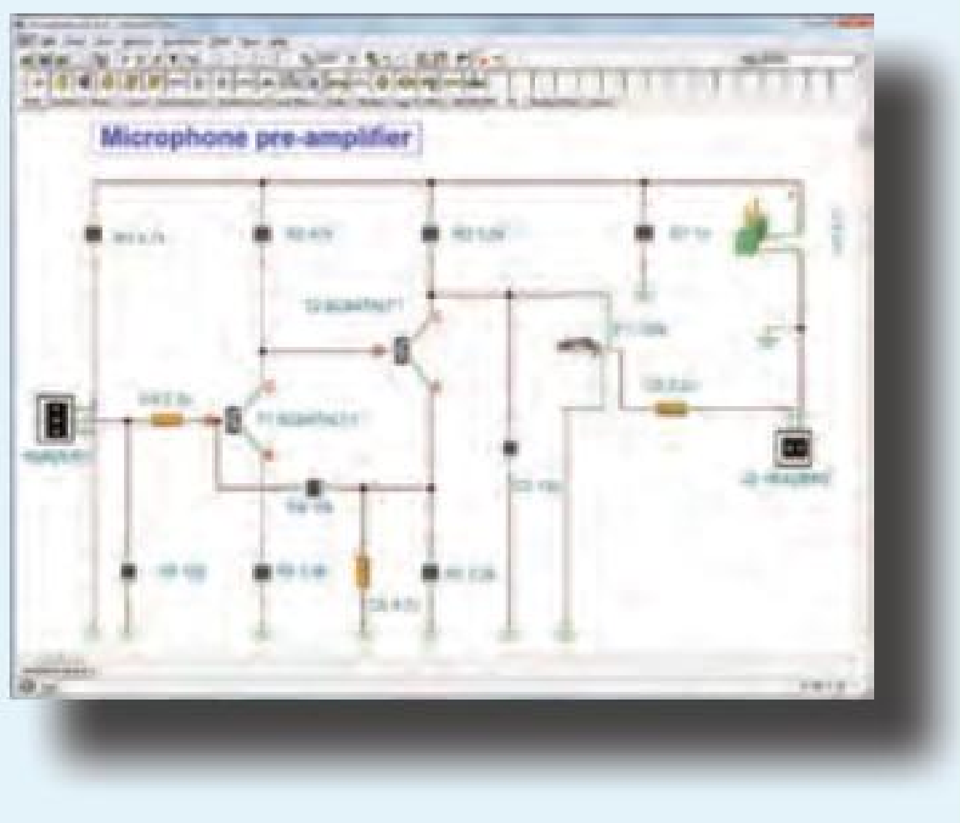
TINA includes the following Virtual Instruments: Oscilloscope, Function Generator, Multimeter, Signal Analyser/Bode Plotter, Network Analyser, Spectrum Analyser, Logic Analyser, Digital Signal Generator, XY Recorder.

3D Viewer
File View Options

This offer gives you a CD-ROM – the software will need registering (FREE) with Designsoft (TINA), details are given within the package.

Get TINA Basic V11 (Hobbyist) for £129 or Student V11 version for £49

Prices include VAT and UK postage



+ get a 1 year free subscription for TINACloud the breakthrough cloud version of TINA which you can run on most operating systems and computers, including PCs, Macs, thin clients iPads and other tablets – even on many smart phones, smart TVs and e-book readers.

To order please either fill out and return the order form, or call us on 01202 880299

Alternatively you can order via our secure online shop at: www.epemag.com

PICmicro TUTORIALS AND PROGRAMMING

HARDWARE

PICmicro Multiprogrammer Board and Development Board

Suitable for use with the three software packages listed below

This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories

£118 including VAT and postage

SOFTWARE

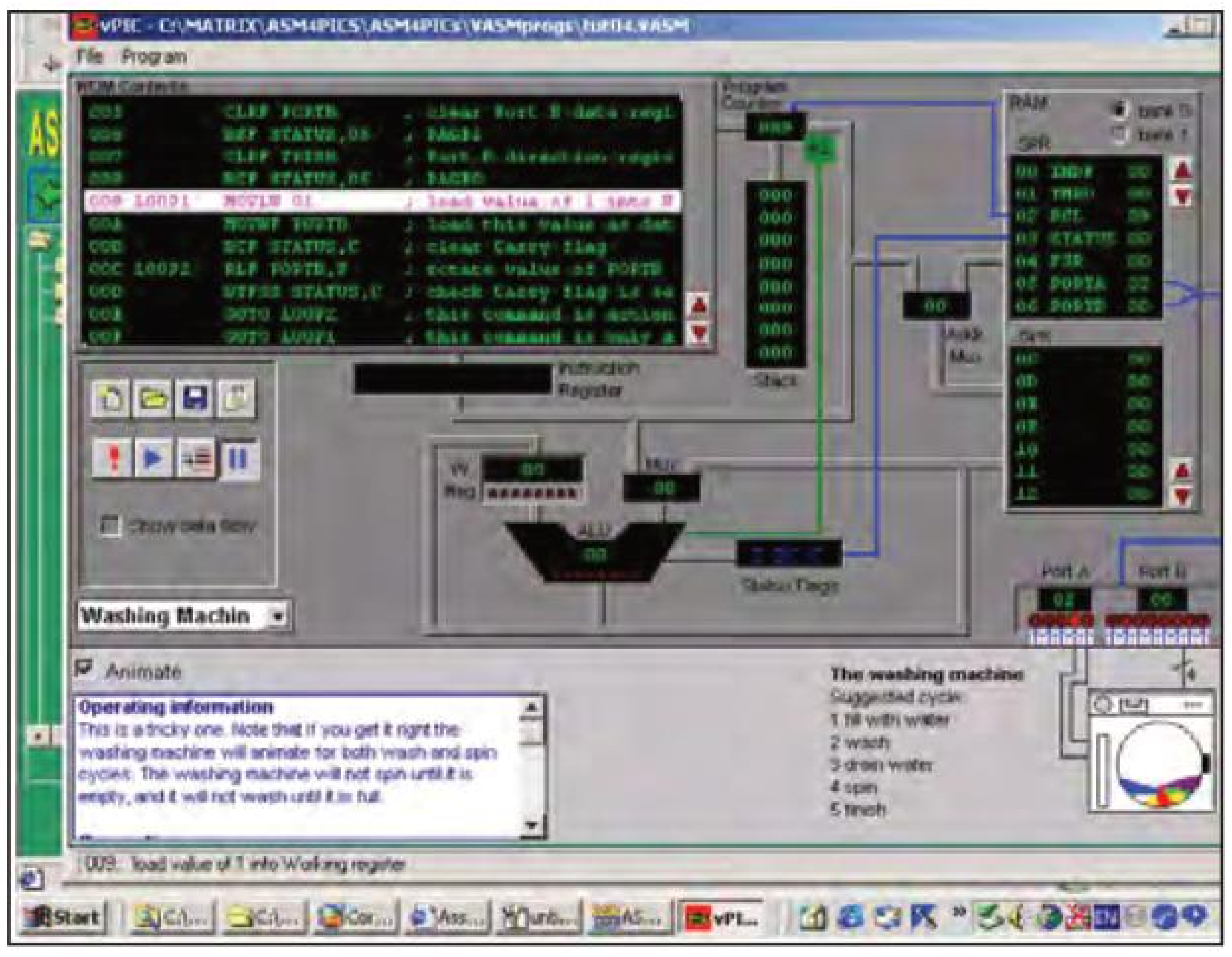
ASSEMBLY FOR PICmicro V6

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

- Comprehensive instruction through 45 tutorial sections
- Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator
- Tests, exercises and projects covering a wide range of PICmicro MCU applications
- Includes MPLAB assembler
- Visual representation of a PICmicro showing architecture and functions
- Expert system for code entry helps first time users
- Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.)
- Imports MPASM files.

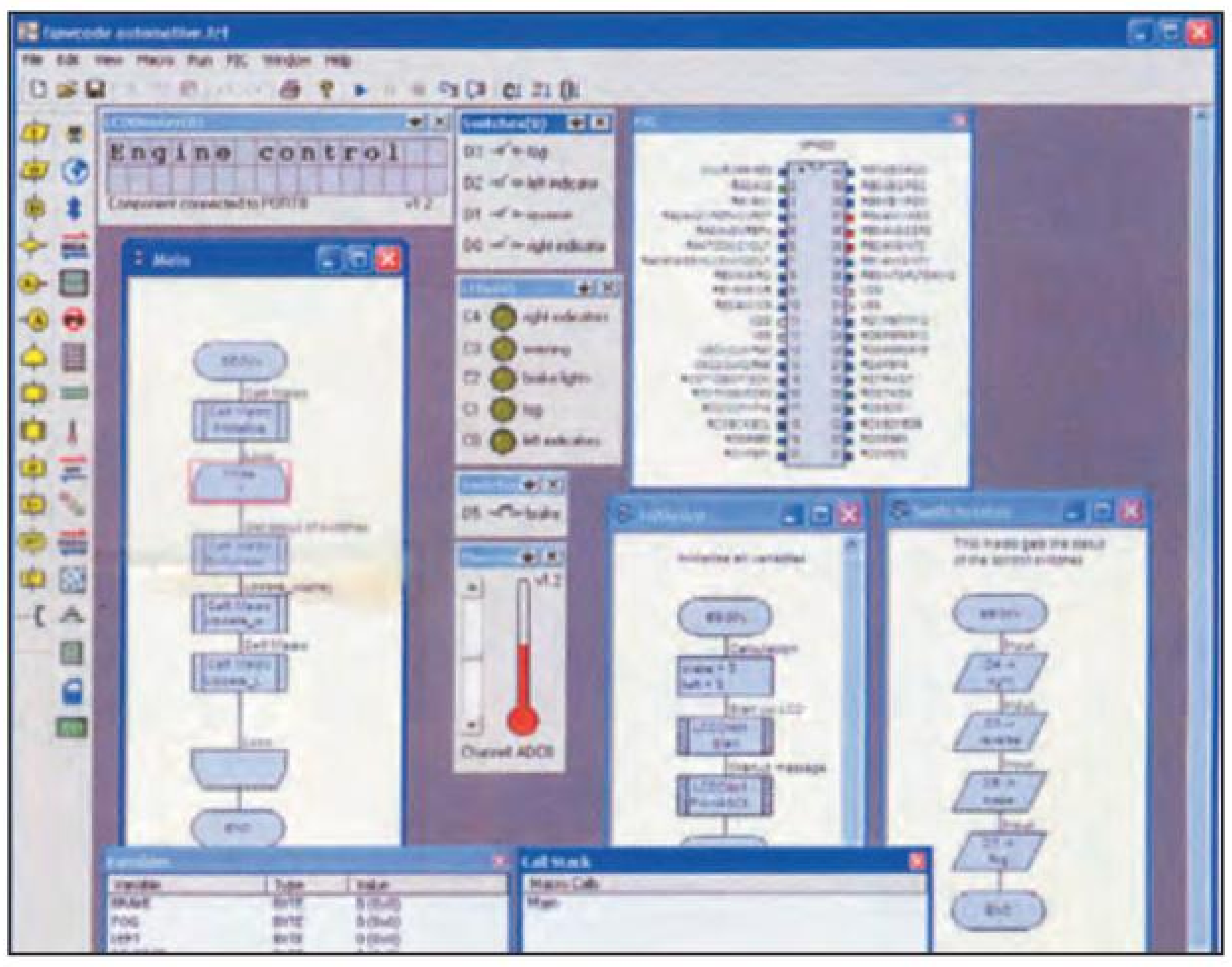


FLOWCODE FOR PICmicro V8

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces code for a wide range of devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



PRICES

Prices for each of the CD-ROMs above are:

(Order form on next page)

(UK and EU customers add VAT to 'plus VAT' prices)

Single License	**£99**	**plus VAT**
Site Licence	**£499**	**plus VAT**
Flowcode (choose PIC-8b, PIC-16b, PIC-32b, AVR/Arduino,ARM)	**Contact us for pricing**	

ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM
USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

CD-ROM **Order code ETI2 CD-ROM** **£9.50**

ELECTRONICS TEACH-IN BUNDLE – FOR PARTS 3, 4 & 5

CD-ROM **Order code ETIB3 CD-ROM** **£18.95**

ELECTRONICS TEACH-IN 3

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

CD-ROM **Order code ETI3 CD-ROM** **£8.50**

ORDERING
ALL PRICES INCLUDE UK POSTAGE

Standard/Student/Basic (Hobbyist) Version price includes postage to most countries in the world EU residents outside the UK add £5 for airmail postage per order

ELECTRONICS TEACH-IN 4

ELECTRONICS TEACH-IN 4 CD-ROM
A BROAD-BASED INTRODUCTION TO ELECTRONICS.

The Teach-In 4 CD-ROM covers three of the most important electronics units that are currently studied in many schools and colleges. These include, Edexcel BTEC level 2 awards and the electronics units of the Diploma in Engineering, Level 2.

The CD-ROM also contains the full Modern Electronics Manual, worth £29.95. The Manual contains over 800 pages of electronics theory, projects, data, assembly instructions and web links.

A package of exceptional value that will appeal to all those interested in learning about electronics or brushing up on their theory, be they hobbyists, students or professionals.

CD-ROM **Order code ETI4 CD-ROM** **£8.99**

ELECTRONICS TEACH-IN 5

FREE CD-ROM
ELECTRONICS TEACH-IN 5
£8.99
FROM THE PUBLISHERS OF
JUMP START
15 design and build circuit projects dedicated to newcomers or those following courses in schools and colleges
PRACTICALLY SPEAKING
The techniques of project construction
PIC 'N MIX
Starting out with PIC microcontrollers
FREE CD-ROM
TEACH-IN 2
TWO TEACH-INs FOR THE PRICE OF ONE!
The free CD-ROM provides a practical introduction to PIC microcontrollers
Plus MikroElektronika, Microchip and L-Tek PoScope software
Electronics Teach-In 2

ELECTRONICS TEACH-IN 5
JUMP START

FREE CD-ROM

15 design and build circuit projects dedicated to newcomers or those following courses in school and colleges. The projects are: Moisture Detector, Quiz Machine, Battery Voltage Checker, Solar-Powered Charger, Versatile Theft Alarm, Spooky Circuits, Frost Alarm, Mini Christmas Lights, iPod Speaker, Logic Probe, DC Motor Controller, Egg Timer, Signal Injector Probe, Simple Radio Receiver, Temperature Alarm.

PLUS:

PIC' N MIX – starting out with PIC Microcontrollers and PRACTICALLY SPEAKING – the techniques of project construction.

FREE CD-ROM – The free CD-ROM is the complete Teach-In 2 book providing a practical introduction to PIC Microprocessors plus MikroElektronika, Microchip and L-Tek PoScope software.

160 Pages **Order code ETI5** **£8.99**

Please send me: **CD-ROM ORDER FORM**

☐ **Assembly for PICmicro V6**
☐ **'C' for 16 Series PICmicro V6**

Version required:
☐ **Single Licence**
☐ **Site licence**

Note: The software on each version is the same, only the licence for use varies.

☐ **PICmicro Multiprogrammer Board and Development Board (hardware)**

☐ **Circuit Wizard – Standard**
☐ **Circuit Wizard – Professional**

☐ **GCSE Electronics**

☐ **TINA Design Suite V11 Basic (Hobbyist)**
☐ **TINA Design Suite V11 (Student)**

☐ **Teach-In 2**
☐ **Teach-In 3**
☐ **Teach-In 4**
☐ **Teach-In Bundle (3, 4 and 5)**

Full name: . . . .

Address: . . . .

. . . . Post code: . . . . Tel. No: . . . .

Signature: . . . .

☐ I enclose cheque/PO in £ sterling payable to WIMBORNE PUBLISHING LTD for £ . . . .
☐ Please charge my Visa/Mastercard: £ . . . .

Valid From: . . . . Card expiry date: . . . .

Card No: . . . .

Card Security Code . . . .

(The last 3 digits on or just under the signature strip)

Single License and Site License Versions – overseas readers add £5 to the basic price of each order for airmail postage (**do not add VAT** unless you live in an EU (European Union) country, then add VAT at 20% or provide your official VAT registration number).

Send your order to:
Direct Book Service
Wimborne Publishing Ltd
113 Lynwood Drive, Merley,
Wimborne, Dorset BH21 1UU

To order by phone ring

01202 880299. Fax: 01202 843233

Goods are normally sent within seven days

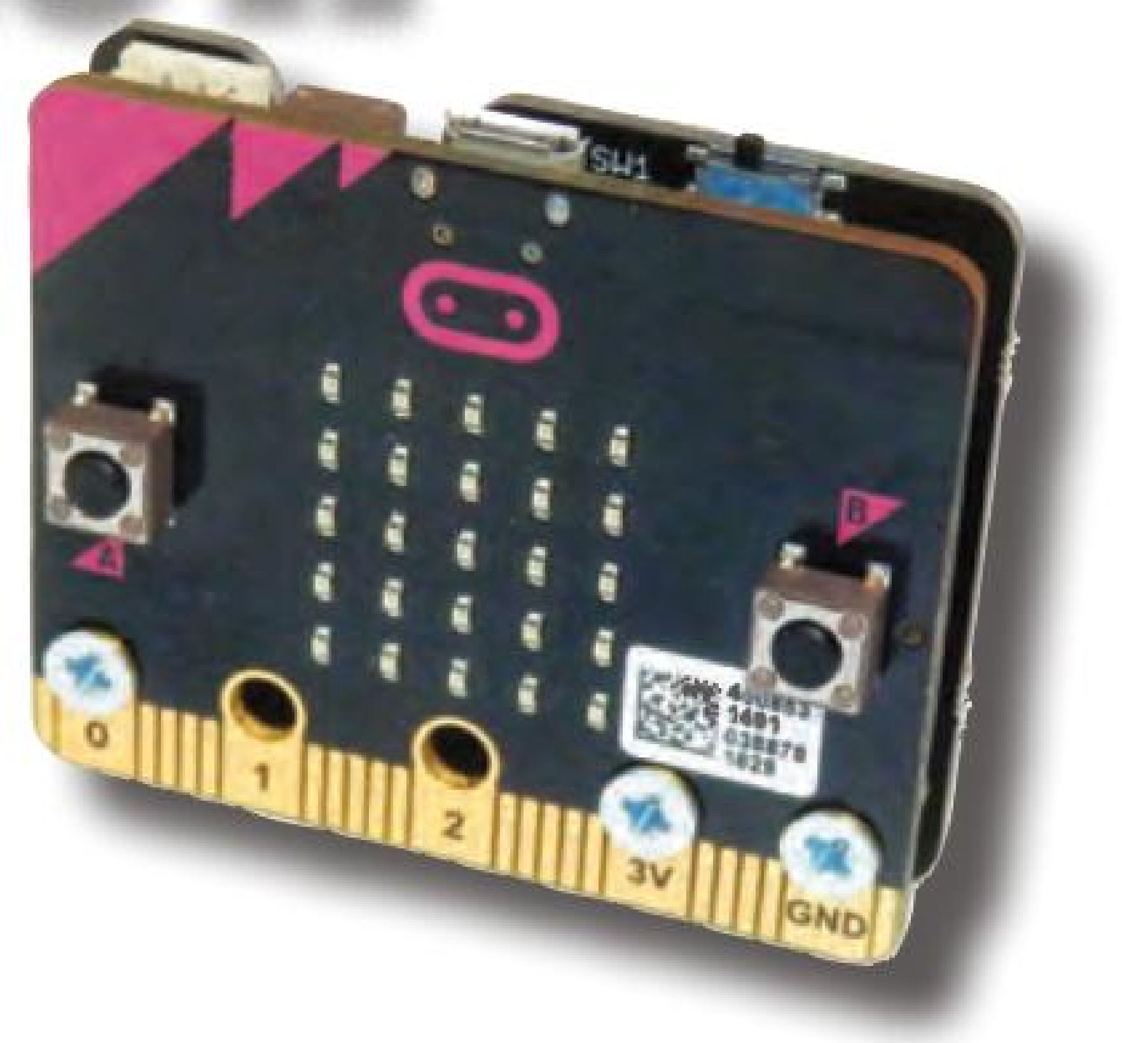
E-mail: fay.kearn@wimborne.co.uk

Online shop:

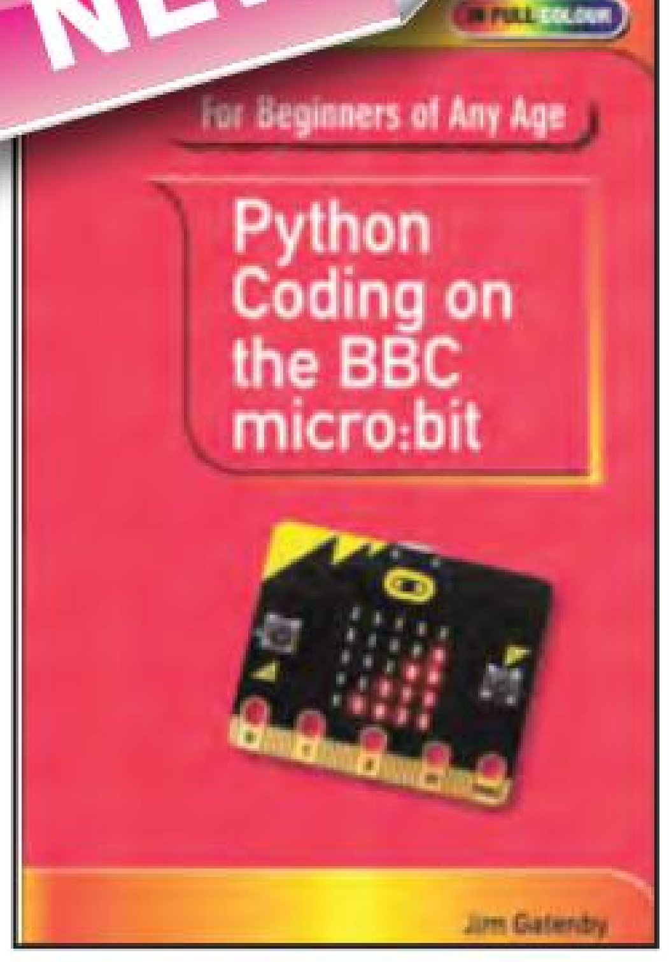
www.epemag.com

DIRECT BOOK SERVICE

Teach-In 2017
Introducing the BBC micro:bit



NEW



PYTHON CODING ON THE BBC MICRO:BIT
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: The main features of the BBC micro:bit including a simulation in a Web browser screen; The various levels of programming languages; The Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; Scrolling messages, creating and animating images on the micro:bit's LEDs; Playing and creating music, sounds and synthesized speech; Using the on-board accelerometer to detect movement of the micro:bit on three axes; A glossary of computing terms.

This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** **£7.99**

GETTING STARTED WITH THE BBC MICRO:BIT
Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** **£7.99**

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Edition. Ian Sinclair

440 pages **Order code NE21** **£33.99**

STARTING ELECTRONICS – 4th Edition
Keith Brindley

296 pages **Order code ELSEV100** **£18.99**

ELECTRONIC CIRCUITS – FUNDAMENTALS & APPLICATIONS – Updated version Mike Tooley

400 pages **Order code TF43** **£32.99**

FUNDAMENTAL ELECTRICAL AND ELECTRONIC PRINCIPLES – Third Edition C.R. Robertson

368 pages **Order code TF47** **£21.99**

A BEGINNER'S GUIDE TO TTL DIGITAL ICs
R.A. Penfold

142 pages **OUT OF PRINT BP332** **£5.45**

UNDERSTANDING ELECTRONIC CONTROL SYSTEMS
Owen Bishop

228 pages **Order code NE35** **£36.99**

The books listed have been selected by *Everyday Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door. Full ordering details are given on the last page.

FOR A FULL DESCRIPTION OF THESE BOOKS AND CD-ROMS SEE THE SHOP ON OUR WEBSITE
www.epemag.com

All prices include UK postage

MICROPROCESSORS

INTERFACING PIC MICROCONTROLLERS – SECOND EDITION Martin Bates

298 pages **Order code NE48** **£34.99**

PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C – LEARNING TO FLY THE PIC24 Lucio Di Jasio (Application Segments Manager, Microchip, USA)

496 pages +CD-ROM **Order code NE45** **£38.00**

INTRODUCTION TO MICROPROCESSORS AND MICROCONTROLLERS – SECOND EDITION
John Crisp

222 pages **Order code NE31** **£29.99**

THE PIC MICROCONTROLLER
YOUR PERSONAL INTRODUCTORY COURSE – THIRD EDITION. John Morton

270 pages **Order code NE36** **£25.00**

PIC IN PRACTICE (2nd Edition)
David W. Smith

308 pages **Order code NE39** **£24.99**

MICROCONTROLLER COOKBOOK
Mike James

240 pages **Order code NE26** **£36.99**

BOOK ORDERING DETAILS

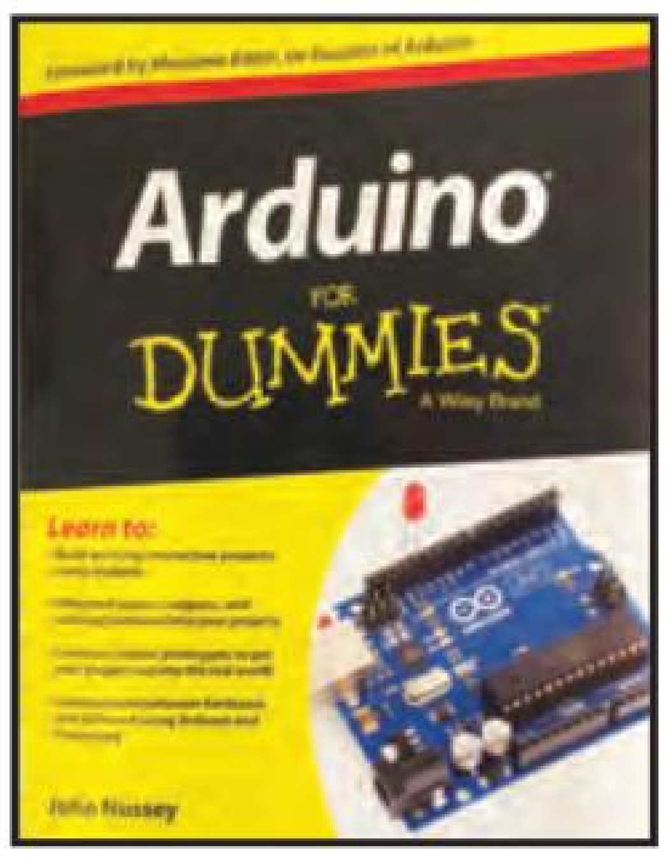
All prices include UK postage. For postage to Europe (air) and the rest of the world (surface) please add £3 per book. Surface mail can take up to 10 weeks to some countries. For the rest of the world airmail add £4 per book. CD-ROM prices include VAT and/or postage to anywhere in the world. Send a PO, cheque, international money order (£ sterling only) made payable to **Direct Book Service** or card details, Visa or Mastercard to: **DIRECT BOOK SERVICE, WIMBORNE PUBLISHING LIMITED, 113 LYNWOOD DRIVE, MERLEY, WIMBORNE, DORSET BH21 1UU**.

Books are normally sent within seven days of receipt of order, but please allow 28 days for delivery – more for overseas orders. *Please check price and availability (see latest issue of* Everyday Practical Electronics*) before ordering from old lists.*

For a full description of these books please see the shop on our website.
Tel 01202 880299 Fax 01202 843233. E-mail: fay.kearn@wimborne.co.uk

Order from our online shop at: www.epemag.com

Teach-In 2016
Exploring the Arduino

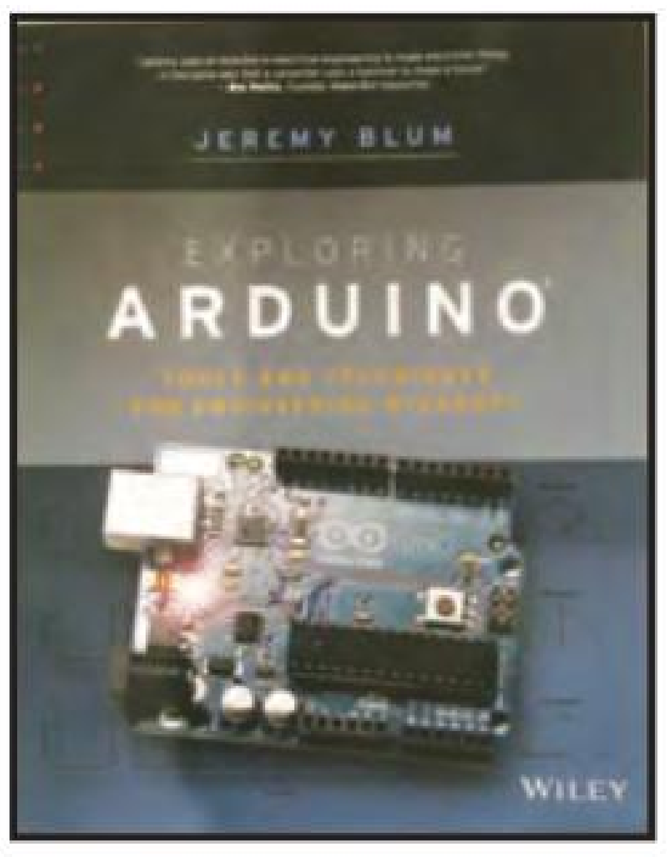


ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- Learn by doing – start building circuits and programming your Arduino with a few easy examples – right away!
- Easy does it – work through Arduino sketches line by line, and learn how they work and how to write your own.
- Solder on! – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
- Kitted out – discover new and interesting hardware to turn your Arduino into anything from a mobile phone to a Geiger counter.
- Become an Arduino savant – find out about functions, arrays, libraries, shields and other tools that let you take your Arduino project to the next level
- Get social – teach your Arduino to communicate with software running on a computer to link the physical world with the virtual world

438 Pages Order code ARDDUM01 £19.99



EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

• Explore the features of several commonly used Arduino boards • Use the Arduino to control very simple tasks or complex electronics • Learn principles of system design, programming and electrical engineering • Discover code snippet, best practices and system schematics you can apply to your original projects • Master skills you can use for engineering endeavours in other fields and with different platforms

357 Pages Order code EXPARD01 £26.99

COMPUTING AND ROBOTICS

NEWNES INTERFACING COMPANION
Tony Fischer-Cripps
295 pages Order code NE38 £41.00

HOW TO BUILD A COMPUTER MADE EASY
R.A. Penfold
120 pages Order code BP707 £8.49

EASY PC CASE MODDING
R.A. Penfold
192 pages + CDROM Order code BP542 £8.99

FREE DOWNLOADS TO PEP-UP AND PROTECT YOUR PC
R.A. Penfold
128 pages Order code BP722 £7.99

WINDOWS XP EXPLAINED
N. Kantaris and P.R.M. Oliver
264 pages Order code BP514 £7.99

THE INTERNET – TWEAKS, TIPS AND TRICKS
R. A. Penfold
128 pages Order code BP721 £7.99

eBAY – TWEAKS, TIPS AND TRICKS
R. A. Penfold
128 pages Order code BP716 £7.50

AN INTRODUCTION TO eBAY FOR THE OLDER GENERATION
Cherry Nixon
120 pages Order code BP709 £8.49

HOW TO FIX YOUR PC PROBLEMS
R.A. Penfold
128 pages Order code BP705 £8.49

AN INTRODUCTION TO WINDOWS VISTA
P.R.M. Oliver and N. Kantarris
120 pages Order code BP703 £8.49

WINDOWS 8.1 EXPLAINED
180 Pages Order code BP747 £10.99

COMPUTING FOR THE OLDER GENERATION
Jim Gatenby
308 pages Order code BP601 £8.99

ANDROIDS, ROBOTS AND ANIMATRONS
Second Edition – John Iovine
224 pages Order code MGH1 £16.99

ROBOT BUILDERS COOKBOOK
Owen Bishop
366 pages Order code NE46 £26.00

INTRODUCING ROBOTICS WITH LEGO MINDSTORMS
Robert Penfold
288 pages + Order code BP901 £14.99

MORE ADVANCED ROBOTICS WITH LEGO MINDSTORMS – Robert Penfold
298 pages Order code BP902 £14.99

HOW TO FIX YOUR PC PROBLEMS
R. A. Penfold
128 pages Order code BP705 £8.49

WINDOWS 7 – TWEAKS, TIPS AND TRICKS
Andrew Edney
120 pages Order code BP708 £8.49

GETTING STARTED IN COMPUTING FOR THE OLDER GENERATION
Jim Gatenby
120 pages Order code BP704 £8.49

WINDOWS 8.1 EXPLAINED
Noel Kantaris
180 Pages Order code BP747 £10.99

COMPUTING WITH A LAPTOP FOR THE OLDER GENERATION
R.A. Penfold
120 pages Order code BP702 £8.49

AN INTRODUCTION TO EXCEL SPREADSHEETS
Jim Gatenby
18 pages Order code BP701 £8.49

AN INTRODUCTION TO THE NEXUS 7
118 Pages Order code BP744 £8.99

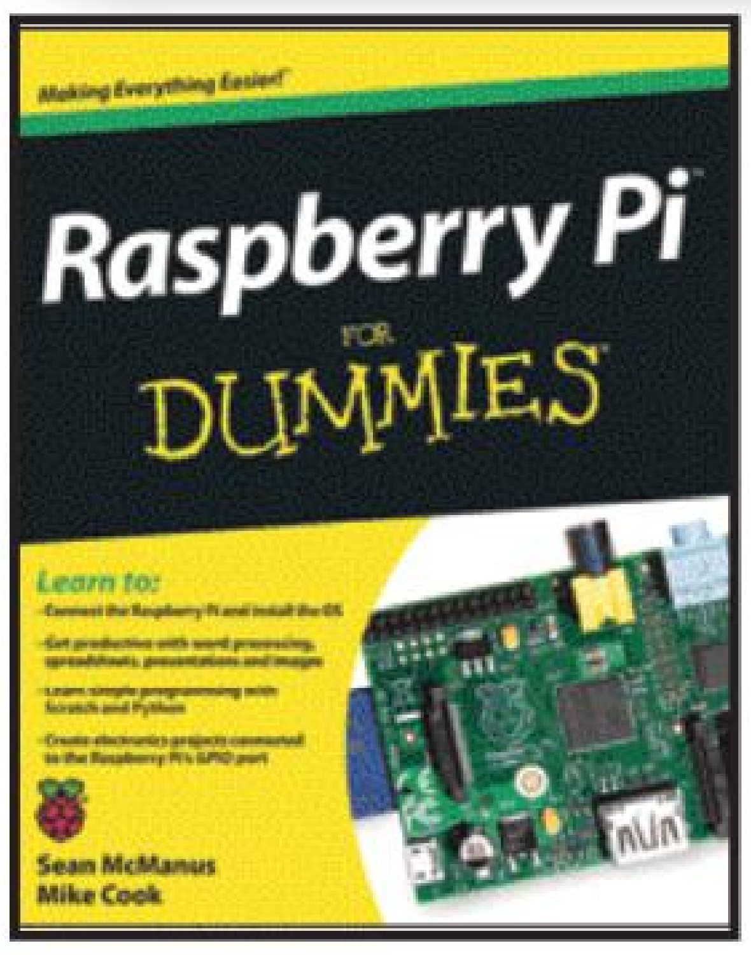
KINDLE FIRE HDX EXPLAINED
118 Pages Order code BP743 £8.99

AUDIO & VIDEO

VALVE AMPLIFIERS – 4th Edition
Morgan Jones
288 pages Order code ELSEV33 £46.99

BUILDING VALVE AMPLIFIERS
Morgan Jones
368 pages Order code NE40 £29.00

RASPBERRY PI



RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

400 Pages Order code RPiDUM01 £17.99

RASPBERRY Pi MANUAL: A practical guide to the revolutionary small computer
176 pages Order code H001 £17.99

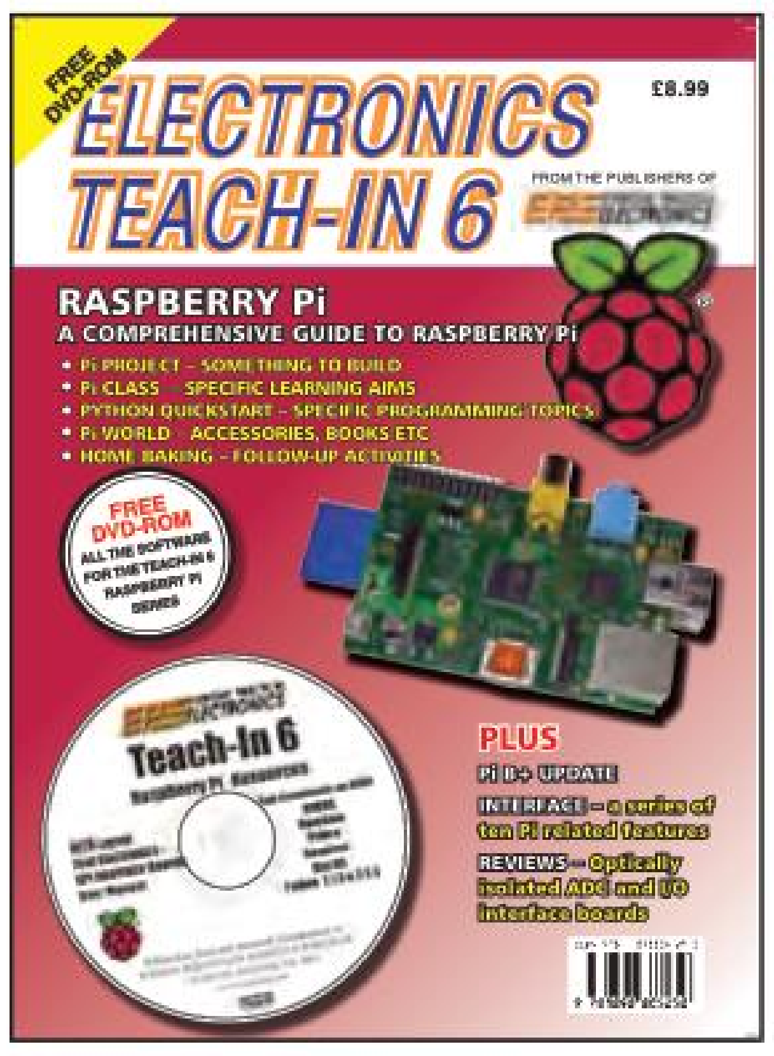
RASPBERRY Pi USER-GUIDE – 4th Edition
262 pages Order code JW001 £20.90

PROGRAMMING THE RASPBERRY Pi
192 pages Order code MGH4 £10.99

GETTING STARTED WITH RASPBERRY Pi
164 pages Order code OR01 £11.50

TEACH-IN BOOKS

ELECTRONICS TEACH-IN 6



ONLY AVAILABLE ON CDROM

ELECTRONICS TEACH-IN 6 – A COMPREHENSIVE GUIDE TO RASPBERRY Pi
Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.

160 Pages **Order code ETI6** **£8.99**

ELECTRONICS TEACH-IN 7 (Includes free CDROM)

ELECTRONICS TEACH-IN 7 – DISCRETE LINEAR CIRCUIT DESIGN
Mike & Richard Tooley

Teach-In 7 is a complete introduction to the design of analogue electronic circuits. Ideal for everyone interested in electronics as a hobby and for those studying technology at schools and colleges. Supplied with a free Cover-Mounted CDROM containing all the circuit software for the course, plus demo CAD software for use with the Teach-In series'

Discrete Linear Circuit Design* Understand linear circuit design* Learn with 'TINA' – modern CAD software* Design simple, but elegant circuits* Five projects to build: Pre-amp, Headphone Amp, Tone Control, VU-meter, High Performance Audio Power Amp. PLUS *Audio Out* – an analogue expert's take on specialist circuits; *Practically Speaking* – the techniques of project building

160 Pages **Order code ETI7** **£8.99**

ELECTRONICS TEACH-IN 8 (Includes free CDROM)

ELECTRONICS TEACH-IN 8 – INTRODUCING THE ARDUINO
Mike & Richard Tooley

Hardware – learn about components and circuits; Programming – powerful integrated development system; Microcontrollers – understand control operations; Communications – connect to PCs and other Arduinos

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The Free CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

160 Pages **Order code ETI8** **£8.99**

CHECK OUT OUR WEBSITE FOR MORE BOOKS WWW.EPEMAG.COM

BOOK ORDER FORM

Full name: ....

Address: ....

....

....

.... Post code: .... Telephone No: ....

Signature: ....

☐ I enclose cheque/PO payable to DIRECT BOOK SERVICE for £ ....

☐ Please charge my card £ .... Card expiry date.......................................

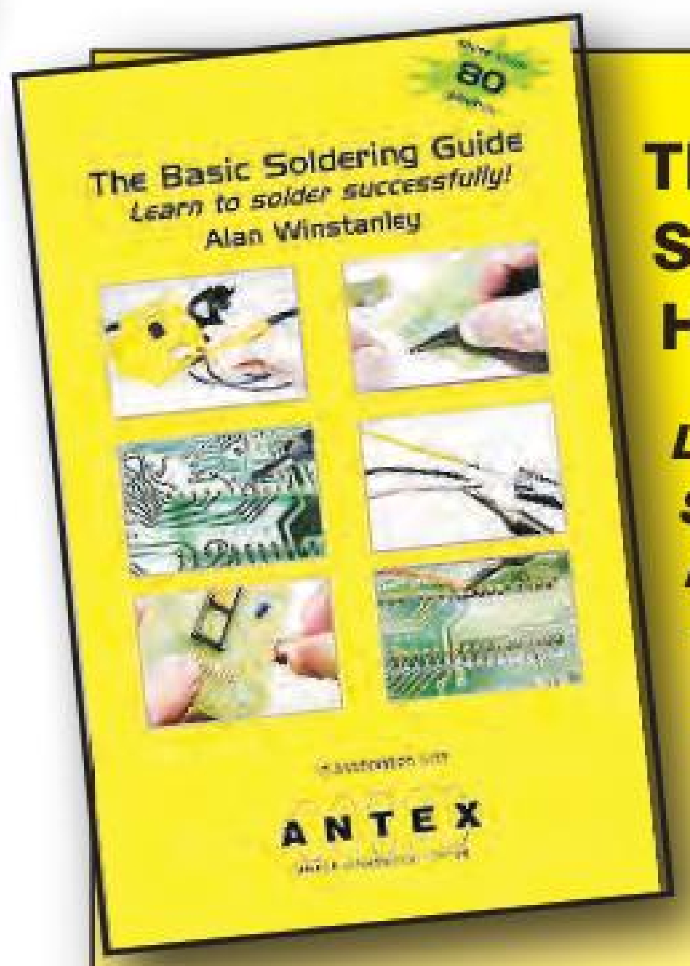
Card Number ....

Valid From Date .... Card Security Code .... (The last three digits on or just below the signature strip)

Please send book order codes: ....

....

Please continue on separate sheet of paper if necessary



THE BASIC SOLDERING GUIDE HANDBOOK

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

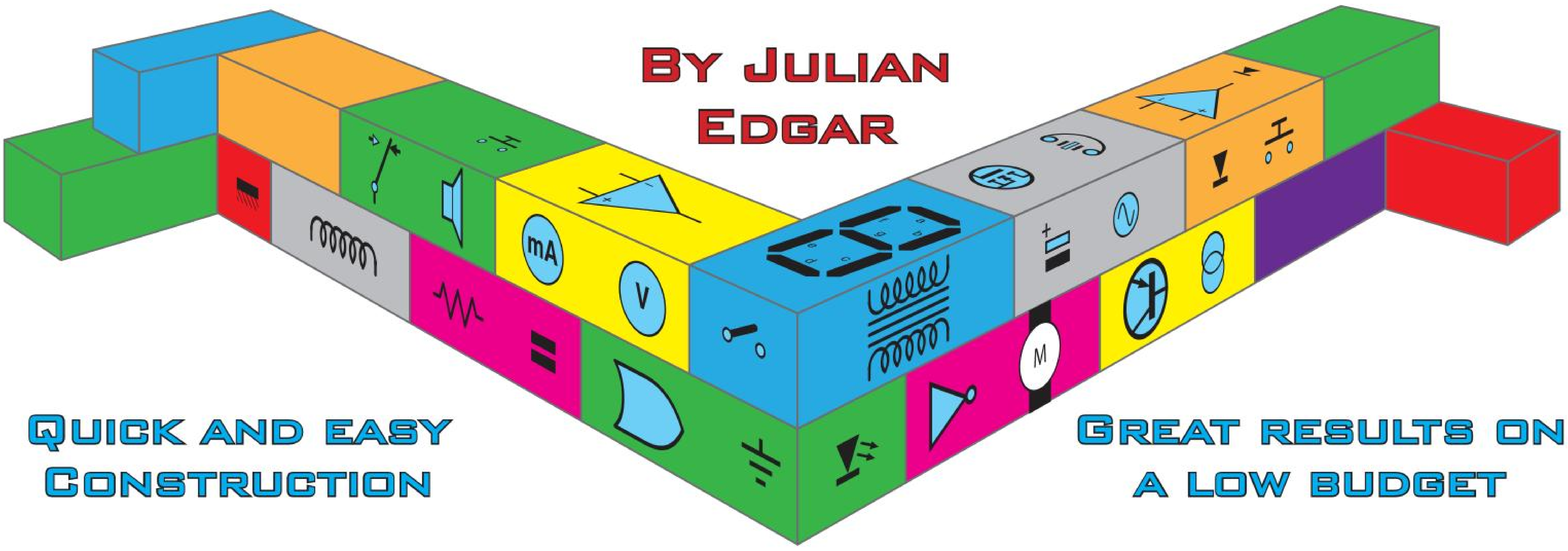
The No.1 resource to learn all the basic aspects of electronics soldering by hand.

With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on Reflow Soldering and Desoldering Techniques, Potential Hazards and Useful Resources. Plus a Troubleshooting Guide.

Also ideal for those approaching electronics from other industries, the Basic Soldering Guide Handbook is the best resource of its type, and thanks to its excellent colour photography and crystal clear text, the art of soldering can now be learned by everyone!

86 Pages **Order code AW1** **£9.99**

ELECTRONIC BUILDING BLOCKS



BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

GREAT RESULTS ON A LOW BUDGET

THREE GREAT BUYS!

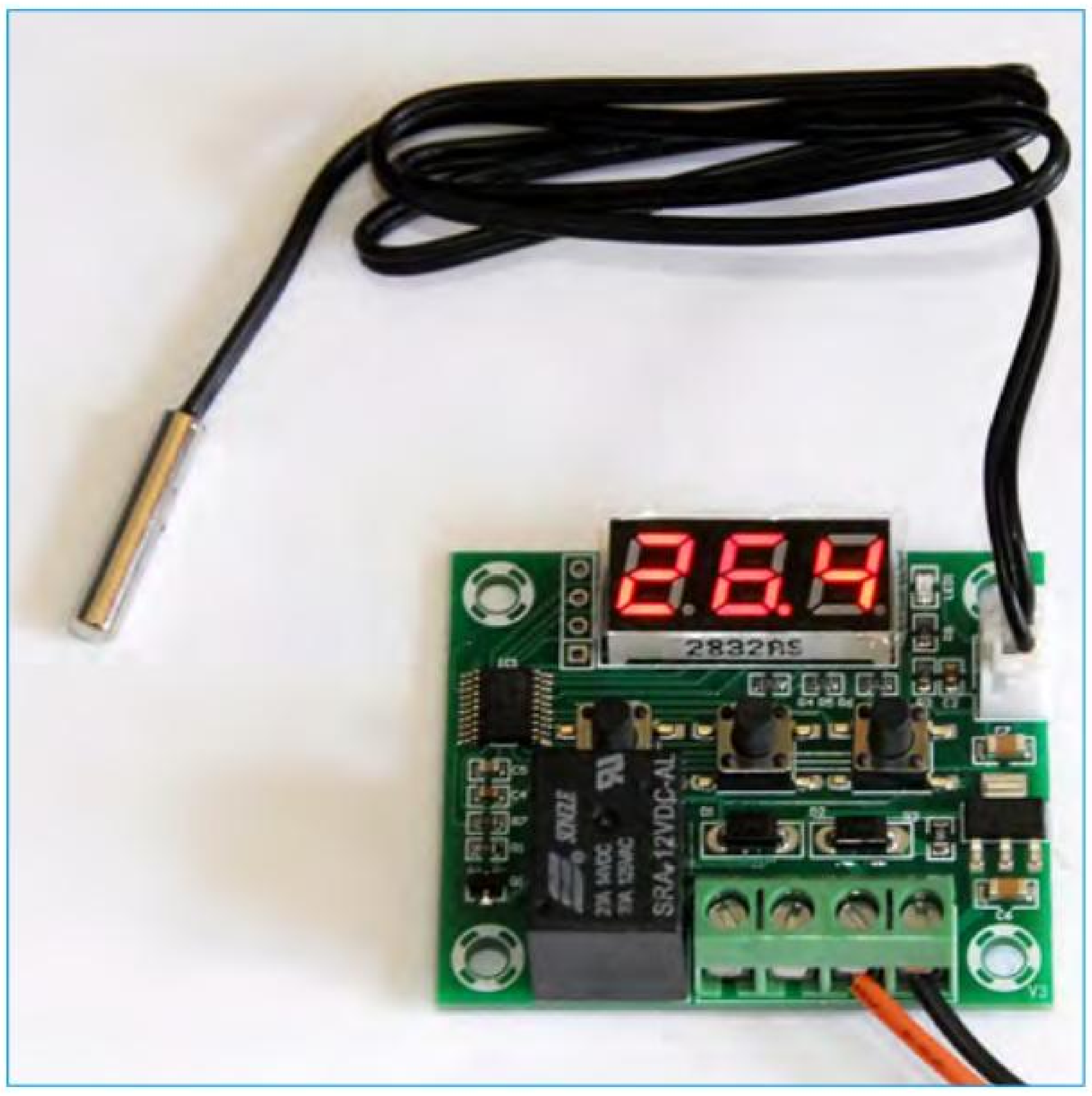
Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

This month, a great trio of *Electronic Building Blocks*: a versatile voltmeter, a brilliant and cheap temperature switch, and an adaptor that turns a discarded PC power supply into a workbench PSU.

Button-style digital 5-24V voltmeter – it's waterproof!

I don't know about you, but I often find myself needing to monitor battery voltages. It might be when charging an SLA battery or perhaps when I want to check on the battery health in my ride-on mower. Of course, you can get out a multimeter – but it's a lot quicker and more convenient if the meter is already there. So with the proliferation of cheap digital voltmeter modules, is that a problem?

Yes it is, for two reasons. First, most voltmeters are hard to mount – you need to cut out a rectangular opening and then laboriously file it to shape. And second, they're not weatherproof and so if the voltmeter is to be used outside, there's another bunch of issues.



This tiny temperature switch is ideal for triggering cooling fans or over-temperature warnings. It measures and displays temperatures over the range of –50 to +110°C and has a relay output. The price is just £2 including delivery!

As you may have guessed, that's where this voltmeter comes in. It's weatherproof and fits straight into a 30mm diameter round hole. While advertised as being suitable for 12 and 24V systems, it works down to 5V without issues. At voltages of less than 10V, the display shows the measurement to two decimal places (eg, 9.65) and at 10V and above it shows the reading to one decimal place (eg, 10.3). Compared with a recently calibrated multimeter, the display in the unit I bought was very accurate. Current draw is low – around 6mA.

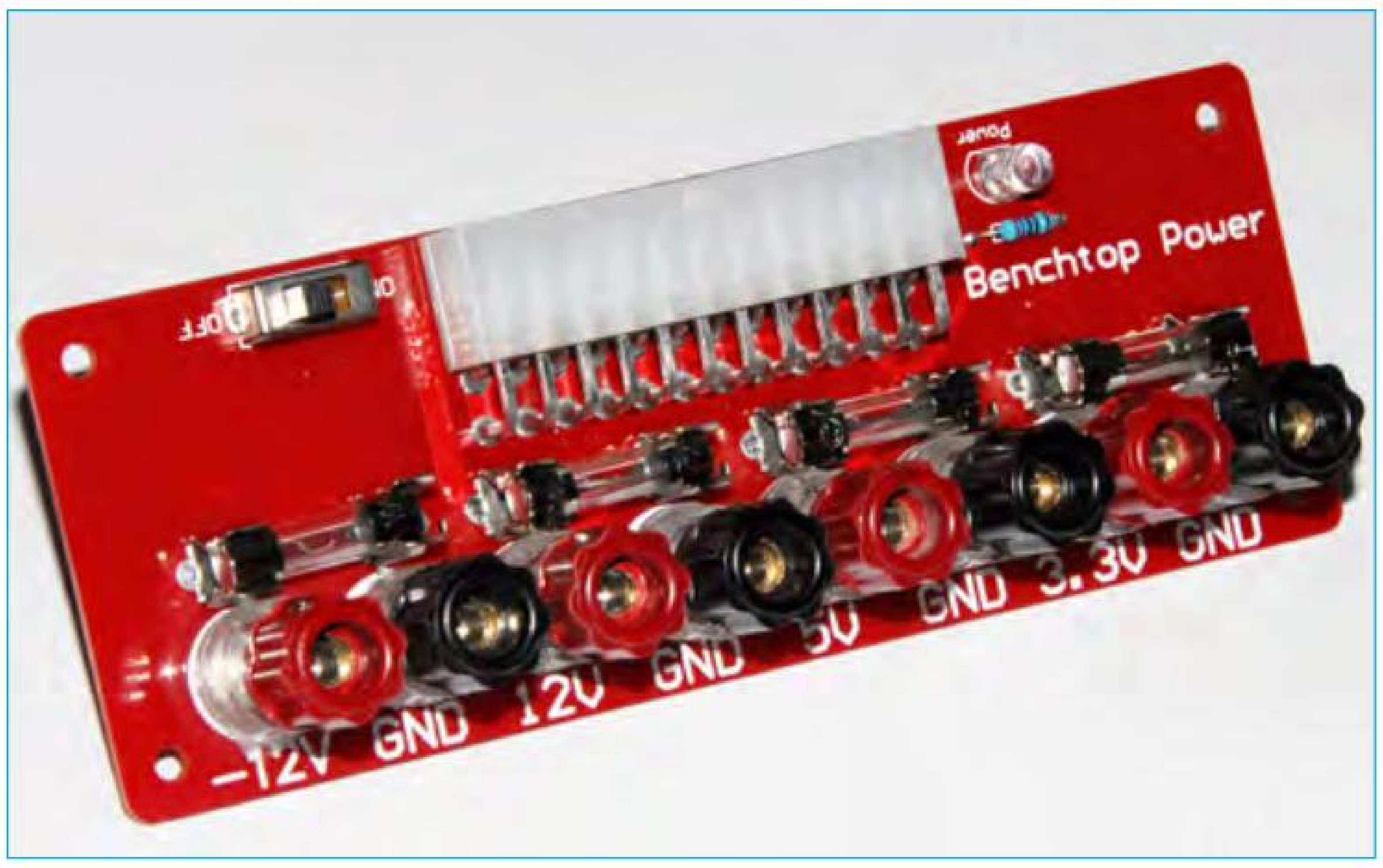
VOLTAGE
8.95
DC
V

This voltmeter is easy to install and waterproof for outside use. Its range is 5-24V and it's quite accurate.

In addition to the blue display shown here, you can buy the meter with white, green, orange or red displays. Cost is around £4 delivered – go to **www.banggood.com** and search under '12V-24V Motorcycle Car LED Digital Volt Meter Waterproof Volt Panel Meter Gauge Black'.

LED display temperature switch – versatile and cheap

Anywhere you're using a large heatsink, you should consider fitting a fan – it helps cater for extremes. Of course, if you size the heatsink correctly, in nearly all conditions the fan won't need to run. But when you crank up the audio sound, or really start to draw some current from that power supply, having extra fan cooling can be an equipment lifesaver. But how to trigger the fan? That's where this module comes in.



Match this board with a discarded ATX power supply and you have a fused bench power supply with four outputs: +12V, –12V, +5V and +3.3V.

At just 48 × 40mm, the tiny module features an LED display that shows monitored temperature (from –50 to +110°C), an SPST relay output, three pushbuttons and a remote temperature sensor on about 500mm of cable. The module runs off a nominal 12V supply.

Connect power, and the LED display shows the temperature. Press the ‘set’ button and the display starts to flash, then use the ‘up’ and ‘down’ keys to set the required switch temperature. One point though: the actual temperature at which the relay pulls-in is 2°C higher than the setpoint. For example, if you set the temperature to 40°C, the relay will pull in at 42°C and then disengage when the temperature falls to 40°C (giving a 2°C hysteresis). The display is bright and the current draw only 23mA.

And the price? Just £2 including delivery! Go to **www.banggood.com** and search under ‘Geekcreit W1209 DC 12V -50 to +110 Temperature Control Switch Thermostat Thermometer’. The same module is also available from other suppliers on **eBay.co.uk** (for example, item 273165343016).

ATX benchtop power supply adaptor – plug-in simplicity

If you’re like me, you’ll be appalled how often working PCs are thrown away. However, unlike some other consumer goods where once they’re outdated, there’s not a lot you can do with them, PCs are different. Why? Because the vast majority have within them a working power supply – and in most cases it’s an ATX design that is plug-in compatible with the module presented here.

And what is the module? It’s very simple, comprising a board with a 24-pin socket, four 5A fuses and screw terminals marked for –12V, 12V, 5V, 3.3V and their corresponding grounds. You remove the working power supply from the discarded PC, plug its 24-pin (or 20 pin) socket into the board, and *voila!* – you now have a new bench power supply featuring the most-used voltages in much electronics work.

Of course, many ATX power supplies can provide more than 5A on their 12V, 5V and 3.3V outputs (and less than 5A on the –12V output) so if you wished, you could alter the fuse values to better reflect the actual power supply capabilities. (Note that if drawing near these maxima, you’d also want to add hard wiring to the PCB to increase its current capability.) For most applications, it’s simplest to just leave the fuse ratings and PCB as they are, and draw only 5A on the three positive supplies.

Cost is around £7 delivered – do an **eBay.co.uk** search under ‘24/20-pin ATX Computer PC Power Supply Bench Top Power Board Module Adapter’ (for example, item 322555068833).

CRICKLEWOOD ELECTRONICS
Established 1981
Frustrated with your supplier? Visit our component packed website for a vast range of parts - old and new, many unavailable elsewhere!
www.cricklewoodelectronics.com
1000’s OF PRICES REDUCED!
Alternatively phone us on 020 8452 0161 with your requirements.
Visit our Shop, Call or Buy online at:
www.cricklewoodelectronics.com
020 8452 0161
Visit our shop at:
40-42 Cricklewood Broadway
London NW2 3ET

Tag-Connect
JTAG Connector Plugs Directly into PCB!!
No Header! No Brainer!
Our patented range of Plug-of-Nails™ spring-pin cables plug directly into a tiny footprint of pads and locating holes in your PCB, eliminating the need for a mating header. Save Cost & Space on Every PCB!!
Solutions for: PIC . dsPIC . ARM . MSP430 . Atmel . Generic JTAG . Altera Xilinx . BDM . C2000 . SPY-BI-WIRE . SPI / IIC . Altium Mini-HDMI . & More
www.PlugOfNails.com
Tag-Connector footprints as small as 0.02 sq. inch (0.13 sq cm)

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

*** See NOTE regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

PROJECT TITLE	ORDER CODE	COST
DEC '16		
Universal Loudspeaker Protector	01110151	£12.88
9-Channel Infrared Remote Control	15108151	£16.42
Revised USB Charger	18107152	£5.36
JAN '17		
High-performance Stereo Valve Preamplifier	01101161	£17.75
High Visibility 6-Digit LED Clock	19110151	£16.42
FEB '17		
Solar MPPT Charger/Lighting Controller	16101161	£17.75
Turntable LED Strobe	04101161	£7.60
MARCH '17		
Speech Timer for Contests & Debates	19111151	£16.42
APRIL '17		
Microwave Leakage Detector	04103161	£8.00
Arduino Multifunctional 24-bit Measuring Shield – RF Head Board	04116011 04116012	£17.75
Battery Pack Cell Balancer	11111151	£9.00
MAY '17		
The Micromite LCD BackPack	07102122	£11.25
Precision 230V/115V 50/60Hz Turntable Driver	04104161	£19.35
JUNE '17		
Ultrasonic Garage Parking Assistant	07102122	£10.45
Hotel Safe Alarm	03106161	£8.00
100dB Stereo LED Audio Level/VU Meter	01104161	£17.75
JULY '17		
Micromite-Based Super Clock	07102122	£10.45
Brownout Protector for Induction Motors	10107161	£12.90
AUG '17		
Micromite-Based Touch-screen Boat Computer with GPS	07102122	£10.45
Fridge/Freezer Alarm	03104161	£8.00
SEPT '17		
Compact 8-Digit Frequency Meter	04105161	£12.88
NOV '17		
50A Battery Charger Controller	11111161	£12.88
Micropower LED Flasher (45 × 47mm)	16109161	£8.00
(36 × 13mm)	16109162	£5.60
Phono Input Converter	01111161	£8.00
DEC '17		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
JAN '18		
High-Power DC Motor Speed Controller – Part 1	11112161	£12.88
Build the SC200 Amplifier Module	01108161	£12.88
FEB '18		
GPS-Syncronised Analogue Clock Driver	04202171	£12.88
High-Power DC Motor Speed Controller – Part 2		
– Control Board	11112161	£12.88
– Power Board	11112162	£15.30
MARCH '18		
Stationmaster – Main Board – Controller Board	09103171 09103172	£17.75
Build the SC200 Amplifier Module – Power Supply	01109111	£16.45
APRIL '18		
Spring Reverberation Unit	01104171	£15.30
DDS Sig Gen Lid	Black	£8.05
DDS Sig Gen Lid	Blue	£7.05
DDS Sig Gen Lid	Clear	£8.05
MAY '18		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£10.45
Microbridge	24104171	£5.60
JUNE '18		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£15.30
JULY '18		
Touchscreen Appliance Energy Meter – Part 1	04116061	£17.75
Automotive Sensor Modifier	05111161	£12.88
AUG '18		
Universal Temperature Alarm	03105161	£7.05
Power Supply For Battery-Operated Valve Radios	18108171 18108172 18108173 18108174	£27.50
SEPT '18		
3-Way Active Crossover	01108171	£22.60
Ultra-low-voltage Mini LED Flasher	16110161	£5.60

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
www.epemag.com

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers –
email **fay.kearn@wimborne.co.uk** stating which masters you would like.

EPE PRINTED CIRCUIT BOARD SERVICE

Order Code **Project** **Quantity** **Price**

. . . .

Name . . . .

Address . . . .

. . . .

Tel. No. . . . .

I enclose payment of £ . . . . (cheque/PO in **£ sterling only**)

to: **Everyday Practical Electronics**

Card No. . . . .

Valid From . . . . Expiry Date . . . .

Card Security No. . . . .

Signature . . . .

Note: You can also order PCBs by phone, Fax or Email or via the Shop on our website on a secure server:
http://www.epemag.com

CLASSIFIED
ADVERTISEMENTS

If you want your advertisements to be seen by the largest readership at the most economical price our classified page offers excellent value. The rate for semi-display space is £10 (+VAT) per centimetre high, with a minimum height of 2·5cm. All semi-display adverts have a width of 5.5cm. The prepaid rate for classified adverts is 40p (+VAT) per word (minimum 12 words).

All cheques, postal orders, etc., to be made payable to Everyday Practical Electronics. **VAT must be added**. Advertisements, together with remittance, should be sent to Everyday Practical Electronics Advertisements, 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU. Phone: 01202 880299. Fax: 01202 843233. Email: stewart.kearn@wimborne.co.uk. For rates and information on display and classified advertising please contact our Advertisement Manager, Stewart Kearn as above.

Everyday Practical Electronics reaches more UK readers than any other UK monthly hobby electronics magazine, our sales figures prove it.

We have been the leading monthly magazine in this market for the last twenty-seven years.

BOWOOD ELECTRONICS LTD
Suppliers of Electronic Components
www.bowood-electronics.co.uk
Unit 10, Boythorpe Business Park, Dock Walk, Chesterfield,
Derbyshire S40 2QR. Sales: 01246 200 222
Send large letter stamp for Catalogue

ADVERTISE HERE FOR JUST £25 +VAT CALL STEWART KEARN ON 01202 880299
STEWART.KEARN@WIMBORNE.CO.UK

Decade Boxes - mdsete.com
Distributor enquires welcome

Looking to advertise?

Contact
Stewart Kearn on:
01202 880299

or email
stewart.kearn@wimborne.co.uk

MISCELLANEOUS

PIC DEVELOPMENT KITS, DTMF kits and modules, CTCSS Encoder and Decoder/ Display kits. Visit **www.cstech.co.uk**

VALVES AND ALLIED COMPONENTS IN STOCK. Phone for free list. Valves, books and magazines wanted. Geoff Davies (Radio), tel. 01788 574774.

ADVERTISERS INDEX

BRUNNING SOFTWARE 10
CRICKLEWOOD ELECTRONICS 69
ESR ELECTRONIC COMPONENTS 47
HAMMOND ELECTRONICS Ltd 9
iCSAT 47
JPG ELECTRONICS 72
LASER BUSINESS SYSTEMS 38
MICROCHIP . . . . Cover (ii), Cover (iii) & 6
PEAK ELECTRONIC DESIGN . . . . Cover (iv)
POLABS D.O.O. 38
QUASAR ELECTRONICS 2
SOUNDTRONICS 3
STEWART OF READING 45
TAG-CONNECT 69

ADVERTISEMENT OFFICES:
113 LYNWOOD DRIVE, MERLEY, WIMBORNE,
DORSET BH21 1UU
PHONE: 01202 880299
FAX: 01202 843233
EMAIL: stewart.kearn@wimborne.co.uk
WEB: www.epemag.com
For editorial address and phone numbers see page 7

Next Month

Content may be subject to change

6GHz+ Touchscreen Frequency & Period Counter – Part 1

We haven't seen the equal of this all-new 6GHz (actually 6GHz+) design anywhere – built up or build-it-yourself. It's based on the Micromite Plus Explore 100 module to give you a superbly easy-to-read, 800 x 480 pixel, 24-bit colour LCD display, along with touchscreen control. It even has an optional GPS module to give you even more accuracy!

3-Way Fully Adjustable Stereo Active Crossover for Loudspeakers – Part 2

In *Part 1*, we described the circuitry and operation of our new *3-Way Adjustable Active Crossover for Loudspeakers*. Now we continue with its construction – building the PCB, testing it, and then putting it in its acrylic case for a truly professional finish. It looks so good and works so well your friends won't believe you built it!

Low-cost Electronic Modules – Part 10

In September's *EPE* we'll look at two really low-cost GPS receiver modules. These devices combine great value for money with impressive performance – making them very attractive for use in all kinds of projects. One is the V.KEL GMouse VK2828U7G5LF, and the other is the u-blox Neo-7M module.

PIC n' Mix

Next month's *PIC n' Mix* column will continue an important new project that will help you learn to build PIC-based projects. The emphasis will be on real-world interface and design techniques – great things to look forward to!

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Techno-Talk*, *Electronic Building Blocks* and *Net Work*.

OCTOBER '18 ISSUE ON SALE 6 SEPTEMBER 2018

WELCOME TO JPG ELECTRONICS

Selling Electronics in Chesterfield for 29 Years

Open Monday to Friday 9am to 5:30pm
And Saturday 9:30am to 5pm

- Aerials, Satellite Dishes & LCD Brackets
- Audio Adaptors, Connectors & Leads
- BT, Broadband, Network & USB Leads
- Computer Memory, Hard Drives & Parts
- DJ Equipment, Lighting & Supplies
- Extensive Electronic Components
  - *ICs, Project Boxes, Relays & Resistors*
- Raspberry Pi & Arduino Products
- Replacement Laptop Power Supplies
- Batteries, Fuses, Glue, Tools & Lots more...

T: 01246 211 202
E: sales@jpgelectronics.com
JPG Electronics, Shaw's Row,
Old Road, Chesterfield, S40 2RB
W: www.jpgelectronics.com

JPG Electronics

Retail & Trade Welcome • Free Parking • Google St View Tour: S40 2RB

CALLING ALL EPE SUBSCRIBERS

If you are one of our valued subscribers then please note that we are changing the way we send subscription renewal reminders.

Instead of sending you a renewal card, we will now print a box on the address sheet, which comes with your copy of *EPE*.

This box will advise you of the last issue in your current subscription.

To renew, you have three choices:

1. Call us on: 01202 880299
2. Visit our website at: **www.epemag.com**
3. Send a cheque to:

Wimborne Publishing Ltd, 113 Lynwood Drive,
Merley, Wimborne, Dorset BH21 1UU

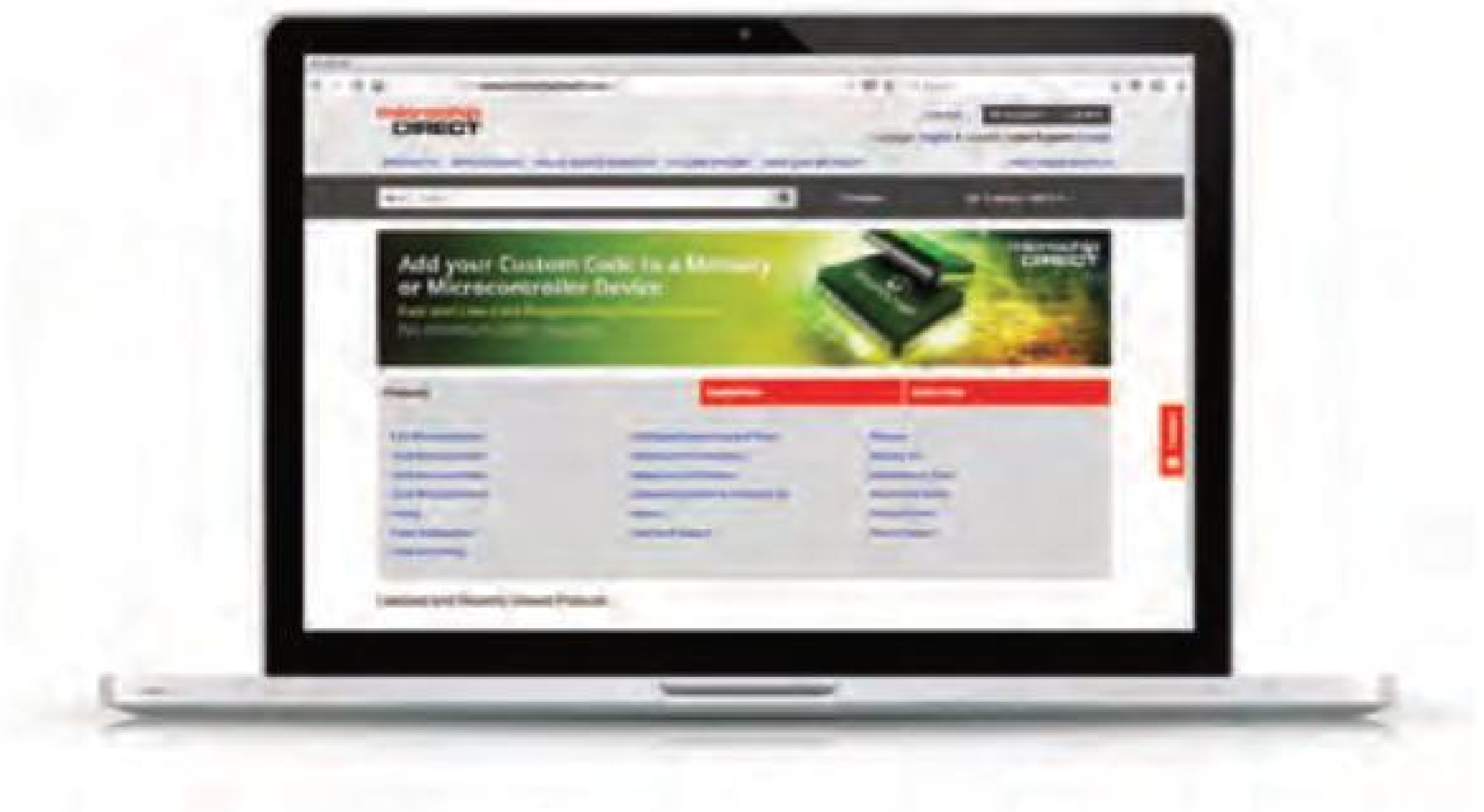
Published on approximately the first Thursday of each month by Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Printed in England by Acorn Web Offset Ltd., Normanton, WF6 1TW. Distributed by Seymour, 86 Newman St., London W1T 3EX. Subscriptions INLAND: £24.00 (6 months); £45.00 (12 months); £85.00 (2 years). EUROPE: airmail service, £30.00 (6 months); £56.00 (12 months); £107.00 (2 years). REST OF THE WORLD: airmail service, £37.00 (6 months); £70.00 (12 months); £135.00 (2 years). Payments payable to "Everyday Practical Electronics'', Subs Dept, Wimborne Publishing Ltd. Email: subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

With Over 250 Million Units in Stock, We've Got You Covered

Delivering You the World's Largest Inventory of Microchip Products

Work directly with Microchip's full service channel to fulfill your supply needs. Take advantage of direct pricing and have access to the world's largest inventory with over 250 million units of Microchip products.

microchip DIRECT



Key Benefits

- Special pricing for high-volume quantities
- Low-cost and secure programming, direct from Microchip
- Schedule orders up to 12 months in the future
- Dropship to multiple addresses worldwide
- Pay by credit line, credit card, PayPal and more

microchip DIRECT
www.microchipdirect.com

MICROCHIP

www.microchip.com/learn-more

The Microchip name and logo and the Microchip logo are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks are the property of their registered owners.
© 2017 Microchip Technology Inc. All rights reserved. DS00002552A. MEC2195Eng11/17

PEAK®
electronic design ltd

10% Online Discount for EPE Readers!

Limited time offer only

Use code
EPE10
during checkout

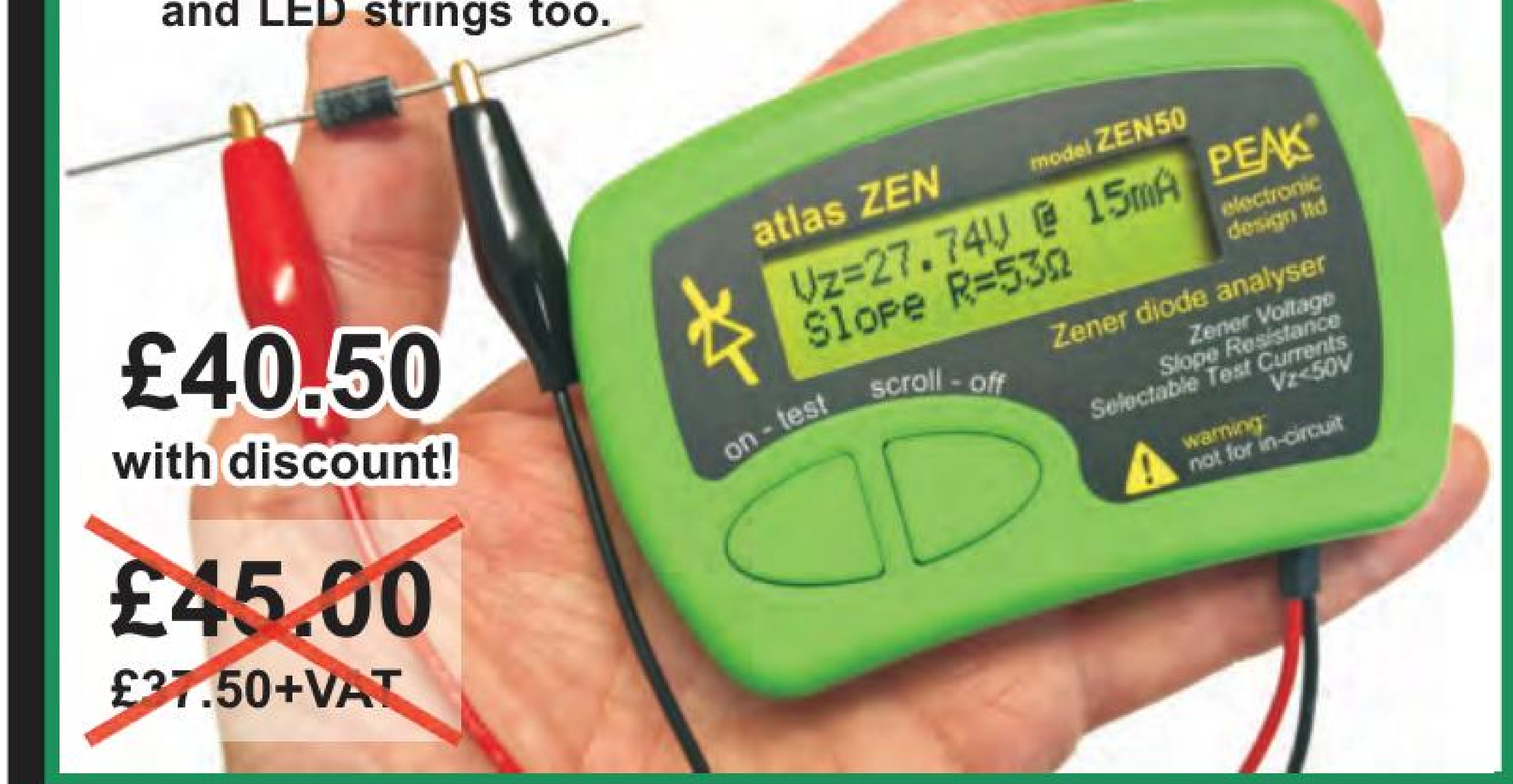
ZEN50

Zener Diode Analyser (inc. LEDs, TVSs etc)

Now with backlit display and AAA battery

The ***Atlas ZEN*** (model ZEN50) is perfect for testing Zeners (including Avalanche diodes), varistors, transient voltage suppressors, LEDs (and LED strings) and many other components.

- **Measure Zener Voltage (from 0.00 up to 50.00V!)**
- **Measure Slope Resistance.**
- **Selectable test current: 2mA, 5mA, 10mA and 15mA.**
- **Very low duty cycle to minimise temperature rise.**
- **Continuous measurements.**
- **Single AAA battery (included) with very long battery life.**
- **Gold plated croc clips included.**
- **Can measure forward voltage of LEDs and LED strings too.**



atlas ZEN
model ZEN50
PEAK electronic design ltd
Vz=27.74V @ 15mA
Slope R=53Ω
Zener diode analyser
Zener Voltage
Slope Resistance
Selectable Test Currents
Vz<50V
on - test
scroll - off
warning: not for in-circuit

£40.50
with discount!

~~**£45.00**~~
~~£37.50+VAT~~

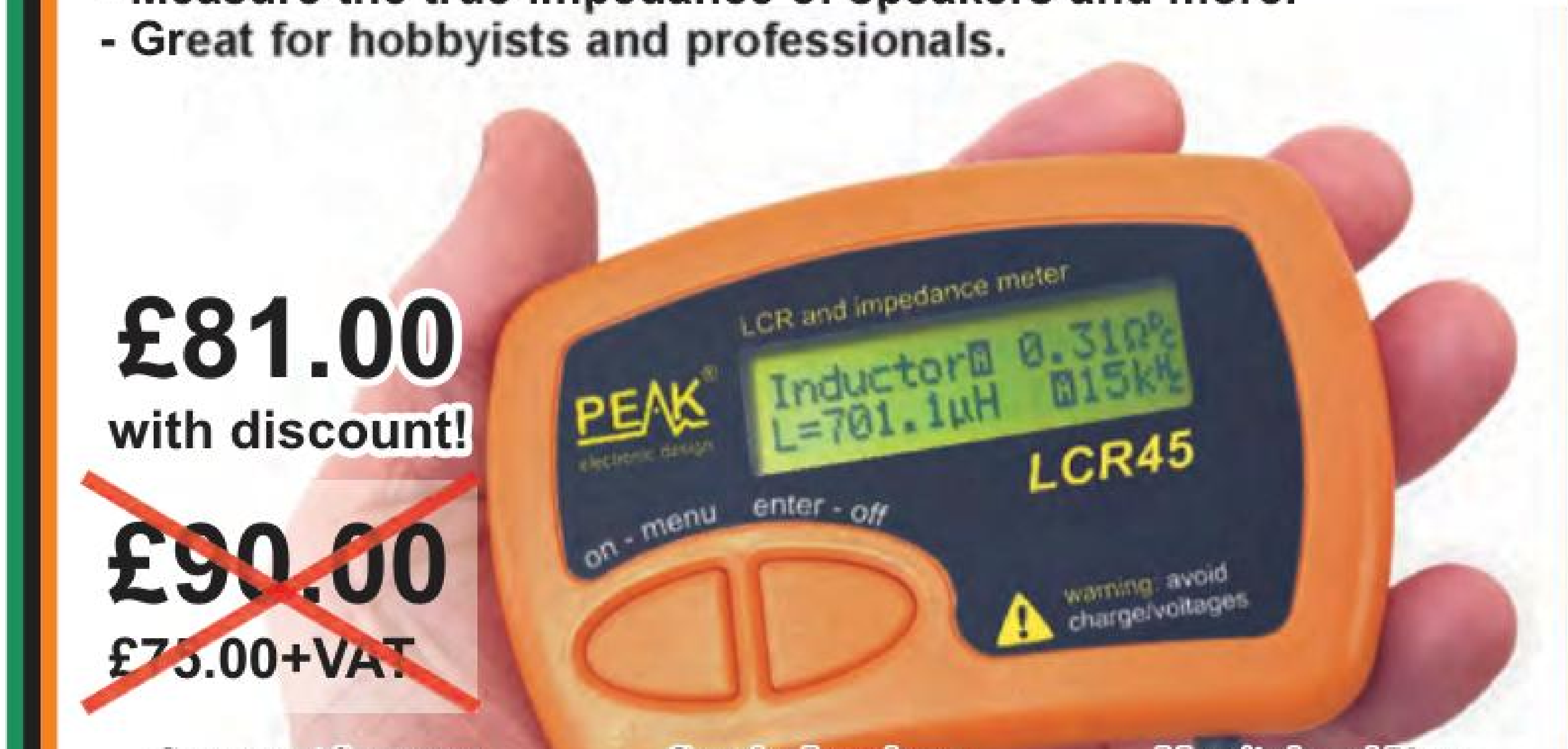
LCR45

LCR and Impedance Meter with Auto and Manual modes

Great for hobbyists and professionals

Introducing a powerful LCR meter that not only identifies and measures your passive components (Inductors, Capacitors and Resistors) but also measures complex impedance, magnitude of impedance with phase and admittance too! Auto and Manual test modes allow you to specify the test frequency and component type.

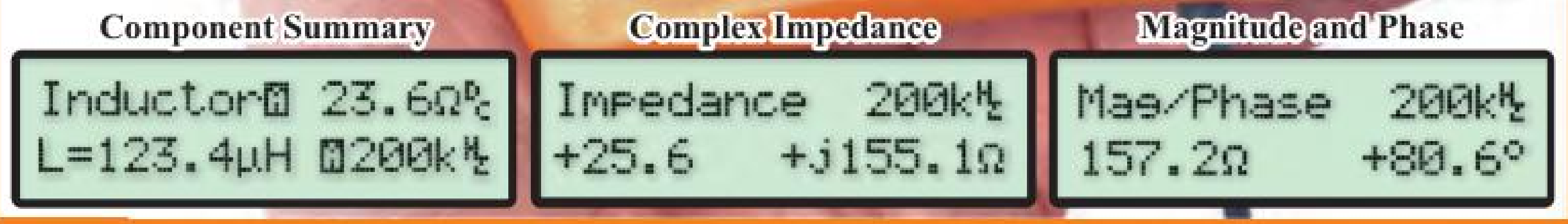
- **Continuous fluid measurements.**
- **Improved measurement resolution: (<0.2µH, <0.2pF).**
- **Test frequencies: DC, 1kHz, 15kHz, 200kHz.**
- **Measure the true impedance of speakers and more.**
- **Great for hobbyists and professionals.**



LCR and impedance meter
PEAK electronic design
Inductor 0.31Ω
L=701.1µH 15kHz
LCR45
on - menu
enter - off
warning: avoid charge/voltages

£81.00
with discount!

~~**£90.00**~~
~~£75.00+VAT~~



Component Summary
Inductor 23.6Ω
L=123.4µH 200kHz

Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω

Magnitude and Phase
Mag/Phase 200kHz
157.2Ω +80.6°

DCA55

Semiconductor Analyser - Identify your semi's

With backlit display and AAA battery

Connect any way round to identify the type of component and the pinout! Also measures many parameters including transistor gain, base-emitter voltages, MOSFET thresholds, LED voltages etc. Complete with a comprehensive illustrated user guide. Includes an Alkaline battery so you're ready to go straight away.

- **Transistors (including NPN/PNP, darlingtons, Si & Ge).**
- **Measure h_{FE}, V_{BE} and leakage.**
- **Diodes and LEDs. Measure V_F.**
- **MOSFETs. Measure V_{GS}(th).**
- **Gold plated hook probes.**
- **Long battery life.**
- **Free technical support for life.**
- **Comprehensive instruction book.**
- **2 year warranty.**

atlas DCA
model DCA55
PEAK electronic design ltd
AAA Battery Edition
Base-Emitter V
VBE=1.039V
semiconductor component analyser
automatic lead identification
on - test
scroll - off
warning: avoid charge/voltages

~~**£51.00**~~
~~£42.50+VAT~~

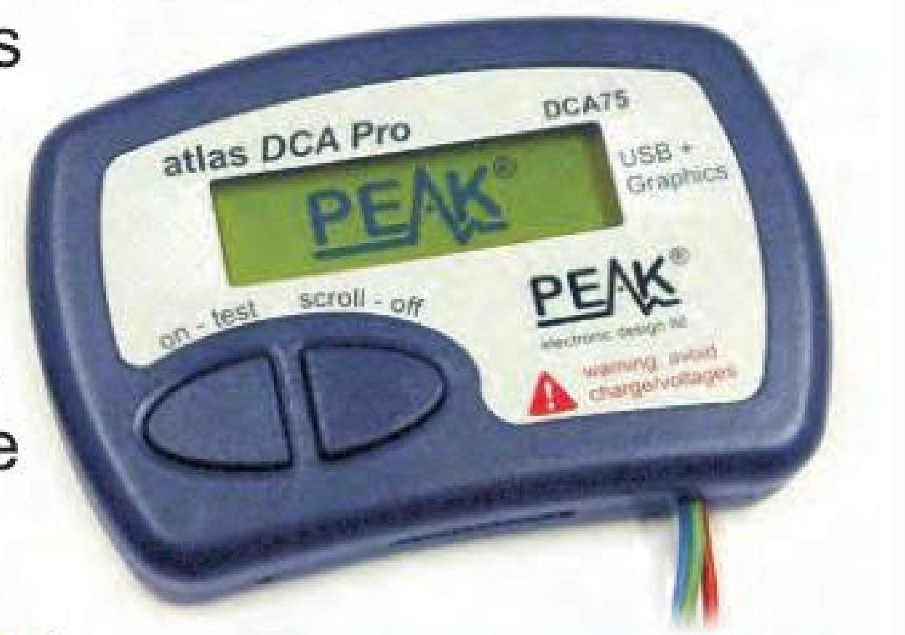
£45.90
with discount!

DCA75

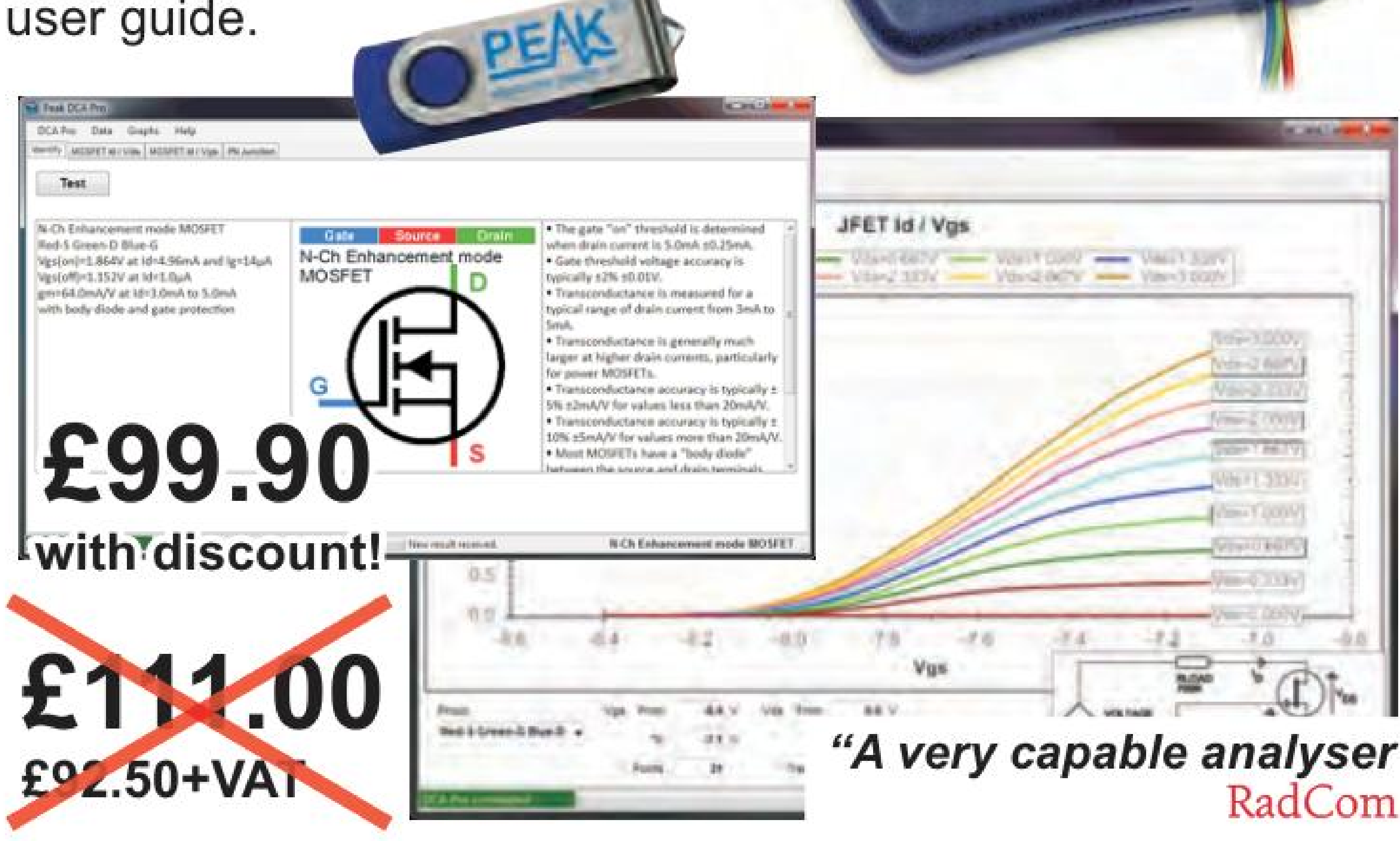
Advanced Semiconductor Analyser and Curve Tracer

Online upgradeable

The popular ***DCA Pro*** features a graphics display showing you detailed component schematics. Built-in USB offers amazing PC based features too such as curve tracing and detailed analysis in Excel. PC software supplied on a USB Flash Drive. Includes Alkaline AAA battery and comprehensive user guide.



atlas DCA Pro
DCA75
USB + Graphics
PEAK
on - test
scroll - off
warning: avoid charge/voltages



PEAK
Peak DCA Pro
DCA Pro
Data
Graphs
Help
Identify
MOSFET Id / Vds
MOSFET Id / Vgs
PN Junction
Test
Gate
Source
Drain
G
D
S
JFET Id / Vgs
Vgs

N-Ch Enhancement mode MOSFET
Red-S Green-D Blue-G
Vgs(on)=1.864V at Id=4.96mA and Ig=14µA
Vgs(off)=1.152V at Id=1.0µA
gm=64.0mA/V at Id=3.0mA to 5.0mA
with body diode and gate protection

N-Ch Enhancement mode MOSFET

- The gate "on" threshold is determined when drain current is 5.0mA ±0.25mA.
- Gate threshold voltage accuracy is typically ±2% ±0.01V.
- Transconductance is measured for a typical range of drain current from 3mA to 5mA.
- Transconductance is generally much larger at higher drain currents, particularly for power MOSFETs.
- Transconductance accuracy is typically ± 5% ±2mA/V for values less than 20mA/V.
- Transconductance accuracy is typically ± 10% ±5mA/V for values more than 20mA/V.
- Most MOSFETs have a "body diode" between the source and drain terminals.

New result received.
N-Ch Enhancement mode MOSFET

£99.90
with discount!

~~**£111.00**~~
~~£92.50+VAT~~

"A very capable analyser"
RadCom

It's only possible to show summary specifications here. Please ask if you'd like detailed data. Further information is also available on our website. Product price refunded if you're not happy.

Tel. 01298 70012
www.peakelec.co.uk
sales@peakelec.co.uk

Atlas House, 2 Kiln Lane
Harpur Hill Business Park
Buxton, Derbyshire
SK17 9JL, UK

UK designed and manufactured